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METALS & ALLOYS

Devoted to the Advancement of Scientific Metallurgy

The Present Status of Cemented Tungsten Carbide Tools and Dies

ZAY JEFFRIES

X-Ray Metallography in 1929

Part V

GEORGE L. CLARK

A New Automatic Metallographic Polishing Machine

S. EPSTEIN—JOHN P. BUCKLEY

NUMBER 5 **VOLUME 1**

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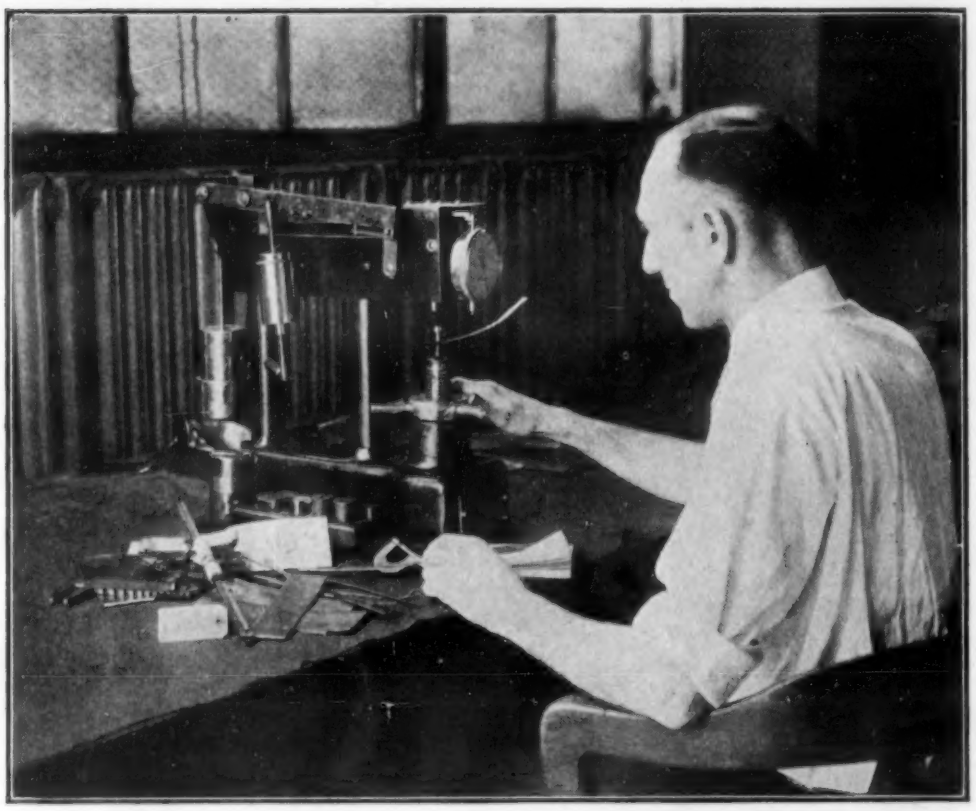

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WHAT A TESTIMONIAL!

"It may interest you to know that we have just gone over our records regarding electric melting, and find that we first installed one of your Ajax-Wyatt Electric Furnaces on October 15th, 1920. Since that time we have added two more units, and we are pleased to say that all furnaces have been practically in continuous operation since their installation. Out of some of these furnaces we have had almost five million lbs. out of one lining, but, of course, our average would run somewhat lower than this; but, taking into consideration all factors, we think it wonderful when we compare these figures with our old type of furnaces.

We distinctly remember with our pit type of furnaces, we had a great deal of trouble in getting proper melters and laborers, and it was a continuous source of trouble trying to keep good melters on the pit type of furnaces; but since the installation of the electric furnaces, we have not only saved a great deal on manual labor and expense, but we feel our men are much more satisfied, as we have eliminated all possible contact with gases and excessive heat, such as we had to contend with in the pit type furnaces. It is also true that our melting losses have been cut practically to nothing, besides getting a more clarified metal.

We cannot refrain from bringing out the point that the installation of the Ajax-Wyatt Electric Melting Furnaces has been the outstanding feature of all the improvements we have made."

TRADE MARK

THE AJAX METAL COMPANY

ESTABLISHED 1880

PHILADELPHIA

CLEVELAND NEW YORK CHICAGO

AJAX

AJAX

PUBLISHER'S PAGE

Note— On this page the publishers will talk right straight to you each month. We will tell you how things are progressing with METALS & ALLOYS. *We will undoubtedly ask your advice on many points. We are publishing this paper not primarily to please ourselves but rather to serve you. And our office door is always open. You are invited to call.*

The Advertising Section of METALS & ALLOYS

It is the feeling of the publishers that the advertising section of such a paper as METALS & ALLOYS should constitute a real source of information and inspiration to those who subscribe for the paper as well as offering to manufacturers a serviceable medium for promoting the sale of their products. At this time of the year we are actively engaged in plans for enlarging our advertising section, and we would greatly value an expression of opinion from our readers on a few important points.

What type of advertising would be of the most interest and value to you? In asking this question we refer to the type of copy rather than to the classes of products; as we take it for granted that our reader will have a very direct interest in all materials, articles and services having any important bearing on the wide range of subjects covered in our editorial section. We should like to know, however, how you regard the advertisements published in this and former issues of the paper. Do you like to see the matter approached from a scientific standpoint as illustrated by the advertisement of the Vanadium Corporation of America on page 4 of the October number? Are you interested in such a presentation as that made by the Kelley-Koett Mfg. Co. on page 9 of the same issue? If you were to take all of the advertisements published in the October number and rate them in the order of their interest to you in what order would you place them?

Is it your opinion that the publisher should make any attempt to standardize, typographically or otherwise, the material appearing in the advertising section? Of course as everyone knows the principal revenue derived by the publisher of any periodical comes from the sale of advertising space. The subscription price does not begin to cover the cost of production—even the mechanical cost without including the editorial staff, the executives, the clerical force and all of those important items designated as "overhead." METALS & ALLOYS, already favored with the advertisements of a small but select group of manufacturers, is anxious not only to derive the necessary revenue from the growth of its advertising section, but is quite as anxious to make this part of the paper of the greatest possible service to the readers, and very profitable to the manufacturers who entrust a part of their advertising appropriations to us.

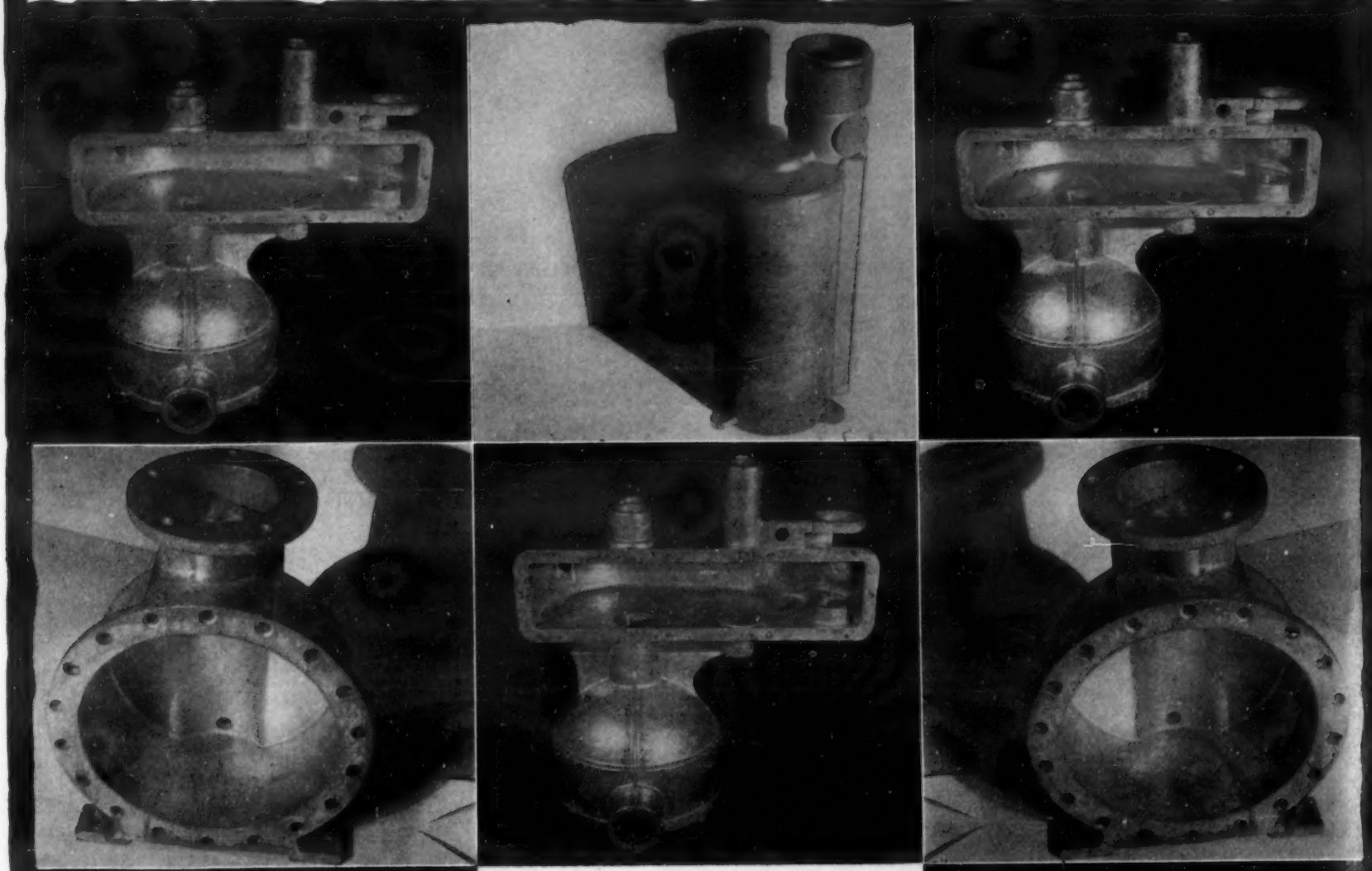
In all lines of endeavor things are changing very fast these days—certainly they are not standing still in the metallurgical field and the business of publishing is experiencing cross currents and growing pains of various kinds.

To say that advertising in a technical paper such as METALS & ALLOYS has reached its highest possible point of efficiency would be just as ridiculous as to maintain that the crude, carelessly planned and frequently misleading advertising which appeared in our journals of twenty-five years ago should be compared with much of the artistic, straightforward, stimulating and useful advertising which appears in our current newspapers and periodicals. When properly used the advertising pages of a technical periodical offer an opportunity to manufacturers to present competitive claims and to give much specific information about their products, which never could consistently be furnished to the subscribers in the reading pages. Provided that a regard for scientific accuracy is maintained (and we think this is almost universally true in technical publications) there is no reason why the information furnished in the form of advertisements, although admittedly competitive, should not be of very great value to all interested in keeping up to date on new materials and processes.

So in developing the advertising section of METALS & ALLOYS if we can assist the manufacturers who use our space to employ it in an even more efficient manner than is at present the case we want to do it. We are sure that any suggestions you may have to make concerning this matter will be most eagerly considered by those who use our space. If any improvement can be made in presenting the stories of these manufacturers for your consideration it will be a pleasure for us, with your assistance, to bring such changes about.

HORSE HEAD *UNIFORM QUALITY* ZINC

FOR THE DIE-CASTING INDUSTRY



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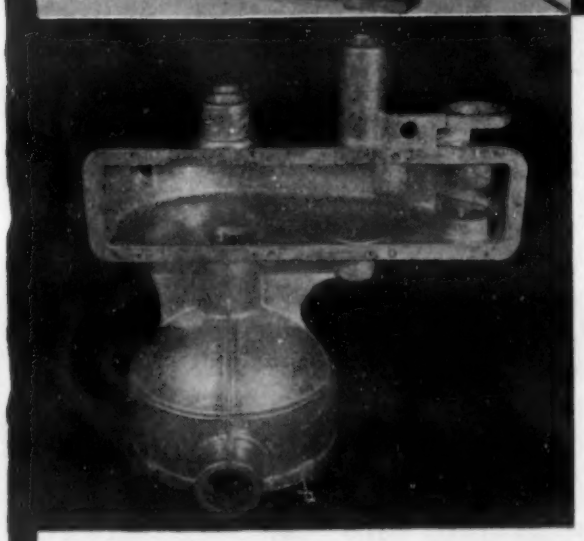

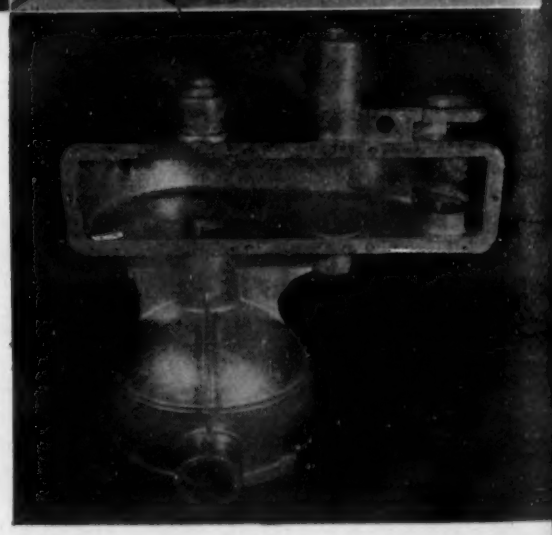

Body and *backbone* are essentials for strength, endurance, and responsibility. ℂ Horse Head—*uniform quality*—Zinc is the *backbone* of these huskies . . . these brutes for punishment . . . these die castings. ℂ Its inherent uniform high quality . . . its long record of responsible service . . . its all around excellence make it the metal with the backbone which has contributed largely to die casting progress. ℂ These qualities also have made Horse Head Zinc the standard high grade zinc for all industries demanding high grade, reliable metal.

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Editorial Comment

In this department I try to comment on metallurgical and allied matters that seem to me interesting and significant. The views expressed reflect my own personal attitude. Many of our readers will have ideas of their own on these subjects and are urged to contribute them in the form of letters which will gladly be published in succeeding issues.—H. W. GILLETT, *Editorial Director.*

Bibliographies, Grooves and Research

The editor of the London *Nature* has recently reiterated the idea that, previous to actual work on a research problem, detailed bibliographic study should be made to acquaint one with what has already been done on the problem, and make it possible to avoid unnecessary repetition of the work of others. This idea seems to be pretty well accepted, and an adequate library is generally considered the one most important research tool.

The editor of *Engineering and Mining Journal* takes strong issue with this under the heading, "Bibliographies of Minor Importance in Research Endeavor." He argues that "while preliminary bibliographical research may conserve some time and effort of workers, little or no gain will thereby accrue to scientific progress." He admits that bibliographies are of value in the acquisition of general information, and that a general knowledge of accomplishments in the field is expected of the research worker. He objects, however, to a "painstaking study of all experimental data" as likely to "thwart new avenues of approach," since "success in research depends on thinking ahead of what others are thinking." He says, "Those who are advancing the borders of scientific knowledge have little opportunity or necessity for looking backward."

We find it difficult to follow the reasoning of the *Engineering and Mining Journal* editorial. If time and effort of workers are saved by study of what has already been done, will not that saved time allow further scientific progress, or are the workers expected to utilize the saved time in playing solitaire? How can one get a general knowledge of a field without reading the literature of it? If one does not need to know what others have done or are doing, but can think himself direct to his research goal, entirely unassisted, why does *Engineering and Mining Journal* carry a "Digest of Current Literature?" To follow the argument through to a conclusion would seem to lead to the elimination from the research man's library of *Engineering Index*, *Chemical Abstracts*, METALS & ALLOYS, and indeed, of all technical journals, including *Engineering and Mining Journal* itself. It seems to us that the man who is incapable of thinking independently when in possession of the information gathered by others, is not very likely to think usefully, whether he reads or ignores the literature.

We can hardly agree with a single phrase of the *Engineering and Mining Journal* editorial as actually stated, yet there is considerable justification for the frame of mind that called it forth. If one has a mere bibliography, or, still worse, has to chase through the indices of all the periodicals that might contain data on the subject in hand, one does undeniably lose much time because of the large amount of material that must be glanced over to find the pertinent and valuable articles that repay detailed study. Even this is better than going ahead with experiments without knowing what the other fellow has done, and has thought.

But a still better way would be to have the bibliographic work done once and for all, and the pertinent data collected into dependable handbooks, text-books, monographs, etc., leaving only the literature accumulating since the date of the compilation for the research worker to worry about when he wants to get the "general knowledge" of the field advocated by *Engineering and Mining Journal*. Such monographs will carry references enough to allow the reader to follow out still more fully any particular subdivision of the subject. As a shining example of a real monograph of this type, we cite the one on "Silica" by Sosman.

The plan of Engineering Foundation for its critical compilation of facts about iron and its alloys—the first step in the "Alloys of Iron Research"—is predicated on the need for sifted and correlated information in usable form. A mere bibliography is but the bare skeleton for such a monograph. Since Engineering Foundation is the research agency of the four major engineering societies, Mechanical, Civil, Electrical and Mining, it may be assumed to speak for a very large group. Not only Engineering Foundation itself, but some three-score metallurgists who were called in for counsel, concluded that such a compilation of facts was the most pressing need of the iron and steel metallurgist.

We believe that a somewhat similar service, on a smaller scale but in a wider field, is rendered by such reviews as the correlated abstracts presented in METALS & ALLOYS. And we submit that the ordinary abstract and the ordinary bibliography also have some value, pending the issuance of monographs, and to cover the field between the dates of issuance of different editions of the monographs which will, of course, have to be brought up to date from time to time.

The mining engineer may often be far from library facilities, and have to depend on a few handbooks, intuition and native ingenuity. Perhaps that is what was in mind in the diatribe against bibliographies. The mining engineer may also run out of tobacco when far from a cigar store, but will he refuse to smoke when he gets back to towns and tobacco? The research worker blessed with library facilities may well wish for some aid that will make their use less time-consuming, but to avoid their use for fear of falling into the grooves worn by previous workers seems short sighted.

We admit that the bowler never makes a strike with a ball that goes down the gutter, and that grooves should not be followed blindly. However, some grooves are worth following. For example, in a study of a new material, it should be tested not only by any new methods designed to appraise its specific properties, but, as well, by the old, accepted and standard methods. Otherwise, no comparison can be made of the material with other materials of the same general class. Study of the literature is necessary in order to find out what methods

previous workers used in defining the properties of the material.

Impact tests are a case in point; with the various types of bars and notches and the impracticability of accurate conversion of results from one to another set of testing conditions, it is a great help if tests are made on a new material by a method by which many other materials have been tested, instead of using only a type of notched bar which, while perhaps as good as any other for comparative purposes, had it been previously chosen as standard, yet does not actually allow a comparison of the results of more than one worker. Without limiting the research workers solely to stereotyped tests, it does seem that enough of the stereotyped tests should be made to allow a tying-in of new data with old.

Sir Oliver Lodge, in his May lecture before the British Institute of Metals, discussed the "states of mind that make or miss discoveries." He even accuses himself of having a "docile mind" which enjoys fitting facts into a theoretical scheme rather than striking out on new lines into revolutionary discoveries. He seems to feel that one has or has not the explorer's mind, but we fail to find any hint in his lecture that he believes the docile mind can be made adventurous by abstaining from the acquiring of information.

It is true that one can be so close to the forest that he can't see it for the trees, but if a research worker is capable at all of independent thinking, he can clear his mind for it by a half-day's fishing, a detective story, or, it is reported, by a round of golf.

If the mind is not too cluttered up, it may be possible to induce the explorer's attitude by contact with an explorer. The contagion of contact with Whitney doubtless accounts for much of the ability of the General Electric research organization to make discoveries off the beaten path. It is difficult to imagine Whitney or any of his close associates being handicapped in their ability to think independently by their knowledge of what others have done.

If a student is so fortunate as to work under a professor of the explorer type, he may gain something of the explorer's point of view that will last through life. Anything that will foster adventurous thinking is worth while. We most heartily agree with *Engineering and Mining Journal* on that, but we believe the thesis that orginality and individualism really cannot exist without ignorance or disregard of the work of others, to be indefensible. We still believe that two heads are better than one.

The Stern Paddle

A birch-bark canoe takes some skill in handling, and balances best with the heavier paddler in the stern. One who is accustomed to handling the stern paddle, and being responsible for steering the canoe, does not relish taking the bow paddle unless his companion is clearly superior in weight, in skill or both. One oddly resents moving from stern to bow; he feels that the bow is the place for the novice.

When by accident, the writer happened to take the bow, and the youngster took the stern this summer, it was something of a shock to realize that the boy weighed as much as his Dad, the canoe balanced as well, and was steered as well as when the place of responsibility was filled by Dad. While the stern position is not yet definitely taken away from Dad, he can't have it all the time now, and in a few more years, his place will be in the bow.

There is many a plant and many a laboratory where the craft would make just as much progress if the younger men were given the stern paddle now and then. The stern paddle is not likely to be given up readily; the older man seldom thinks of it, and the younger man has too much deference to suggest it. Some of the older men do think of it, however. Coming back from vacation with this train of thought in mind, and going at once to "Metals Week," it was interesting to note that the paper on "A Method of Determining the Orientation of the Crystal in Rolled Metal from X-ray Patterns Taken by the Monochromatic Pinhole Method" by Davey, Mitchel and Fuller was presented by the junior author.

We have a distaste for long titles of papers, and for a plurality of authors. Some pity should be had for librarians and abstractors. But that is a subject for another editorial when we get sufficiently worked up over the subject. Whether the paper needed so long a title or not, and whether real authorship resided in three people or not, it was an important and rather abstruse subject, difficult to present so the audience would grasp it. Dr. Davey is a master of clarity. No one would have thought it other than most natural had he chosen to present it himself. It was, however, presented by the junior author, and it got across just as well as if Davey himself had been the speaker. We know quite well why it was so presented. Davey is just as much interested in developing stern paddlers as he is in science, which explains why he is where he is to-day.

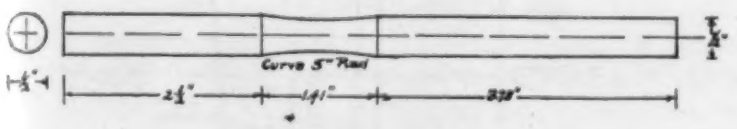
Metallurgy needs stern paddlers. Perhaps you have some in your organization who are still paddling bow. It's not a bad plan to let them try the stern. If they are stern paddlers, they're likely sooner or later to go from the bow of your canoe to the stern of some other canoe. While the old steerman's pride may be hurt to sit in the bow, after all, on a long cruise, it is restful to shift from stern to bow, now and then. We suspect, too, that many people would live to take more and longer cruises if they didn't insist in staying in the stern too long.

Readers' Views and Comments

To the Editor of METALS & ALLOYS:

Dear Sir: I have noticed a very interesting editorial in the September issue of METALS & ALLOYS referring to the high cost of fatigue test specimens. I have given considerable thought to this problem in the past and in this connection I would like to refer you to some of the improvements that have been made along this line. In 1927, Mr. R. L. Templin presented a paper to the A. S. T. M. in which he described a method of preparing sheet tensile test specimens for thin sheet metals. In my comments on this paper which are published in the transactions of the society I described an alternate method. This method of preparing tensile test specimens has since been applied to the preparation of sheet metal fatigue specimens and the form of specimen and method of test employed is described in a paper on Fatigue Studies of Non-Ferrous Sheet Metals by Mr. C. H. Greenall and myself which was presented at the 1929 convention of the A. S. T. M. This method of cross-milling the fatigue test specimens consists in machining out blank strips, stacking these together in a pack and then cross-milling the specimens with a milling cutter ground to the proper shape. The cost of preparing specimens in this way amounts to only a few cents per specimen.

As mentioned in your editorial the main difficulty is with the round or rotating beam fatigue test specimens and I believe that your estimate of $3.00 per specimen as used on the R. R. Moore machine is approximately correct. We have adopted a slightly different form of test for rotating beam fatigue testing. By using a machine similar to the one described by Dr. D. J. McAdam and used by him in his many investigations of fatigue and corrosion fatigue, the specimen is clamped by means of a chuck at one end and the other end is free and has attached to it through a ball bearing a dead weight. The type of fatigue specimen used by Dr. McAdam is also expensive to machine. We have modified the design of this specimen as shown by the



Fatigue Test Specimen for Rotating Lead Beam

sketch. The material can be supplied in the form of centerless ground rod which is then cut to size and the reduced section is turned by using a profile cutting tool mounted on a swivel base with a 5″ radius. The cost of manufacture of specimens by this process is of the order of 50 cents per specimen for a limited number of specimens and would be much smaller for a larger number of specimens. I believe that the McAdam type of machine which is capable of testing from 4 to 8 or more specimens and uses an aligning chuck is the simplest and most satisfactory type of rotating beam testing machine that I have seen. Furthermore, for a given investment this machine will test more specimens. By adopting the simplification of the test specimen which is described herewith and which does not require any sacrifice in accuracy of stress calculation the cost of test specimens may be greatly reduced. I believe this is the answer to the problem cited in your editorial.

Hoping that these comments will be of interest to you and of some service to those who are interested in this problem, I am

J. R. TOWNSEND

Bell Telephone Laboratories,
463 West Street, New York

To the Editor of METALS & ALLOYS:

Dear Sir: I have read with great interest the article on Cost of Specimens. We prepare standard fatigue specimens for Dr. Moore's Machine for $3.50 each in lots of six or more. Sometimes it is profitable; sometimes otherwise. It depends on the metal.

We are pretty well equipped for machining the specimens and have done quite a lot of them. There are a number of successive operations and each and all have to be done just right. It's a man's job, not an apprentice boy's. I don't see how anyone can machine them as a commercial proposition and make ends meet at $3.00 each. Still, most of us get jolted occasionally and realize that some other fellow is a good bit smarter than we are.

W. S. MOREHOUSE

Morehouse Machine Company,
York, Pa.

To the Editor of METALS & ALLOYS:

Dear Sir: Ever since getting the first number of METALS & ALLOYS I have been intending to comply with your request and let you know what I think of the magazine. I am glad that I have put this off until now, because I can take note of some of the criticisms which you mention having received in your canvass of readers during the recent Metals Week. Personally, I do not think there is any room for criticism. We certainly do want "high-brow" technical articles. A former chief of mine once said that nowadays one has to read right through a whole magazine, including the advertisements, to get one new idea. Judged by this standard, METALS & ALLOYS is a great improvement, and in a class by itself. Still, those who have been criticizing the technical nature of the articles from the point of view of the practical man or the manufacturer should realize that advertisements themselves ought to be written by a good technical writer, as anything in the way of bunk or misstatement of fact makes a very bad impression on a prospective purchaser. As I said above, METALS & ALLOYS entirely satisfies me, and, although I subscribe to your hopes that it will grow and become a good revenue producer, I would suggest that this be accomplished in some way by keeping up the quality of the advertisements as well as the editorial matter. The thing I dread is that the magazine should ever attain the proportions of some of the metal trade papers; I should then be afraid to tackle it at all.

In regard to definite suggestions for future articles, I would like to read a series, turned out in digestible doses, on Carboloy; not only an account of what it is doing, but something about its development and the experiments leading up to its perfection. For example, was the experiment tried of making a tungsten-carbide alloy corresponding to carbon steel? Another valuable series of articles would be on Nitriding, which might be built up along the lines of the salient features mentioned in Dr. Fry's address in Cleveland. This would be of very great practical value. Thirdly, articles on corrosion-resisting and heat-resisting steels and alloys might be written to clarify the situation. There are, of course, a great number of brands of these alloys on the market, for some of which extravagant claims are made and exorbitant prices charged. The time must soon come when these materials will all be bought according to specification on a competitive basis.

In closing, I wish to state again my great satisfaction with the magazine as it now is.

GORDON SPROULE

Metallurgical Engineer,
Montreal, Canada.

The Effect of Lead on the (Alpha + Beta)/Beta Equilibrium in a 60/40 Brass (Muntz Metal)[1]

By Leland Russell van Wert[2]

This paper discusses the experimental results of an investigation to determine what, if any, qualitative effects small amounts of lead have on the system alpha (solid solution)⟷beta (solid solution) as present in a 60/40 brass. The effect of a third metal on phase equilibria in bi-phase alloys is always of considerable interest; in this instance, it is also of some practical importance because of the wide use of lead in the duplex brasses of the Muntz Metal type, the properties of which change with a change in the relative amounts of the two co-existing phases and with the way the phases distribute themselves in respect to one another.[3]

The experimental work was done on a series of five brasses, each containing nominally 60 percent copper and 40 percent zinc. Each alloy of the series differed essentially from the others only in the amount of contained lead. This varied from 0.04 percent in alloy *A* to a maximum of 1.76 percent in alloy *E*. The complete analysis of each brass of the series is given in Table 1.

Table 1. Composition of Brasses Investigated

Alloy	Cu	Pb	Fe	Sn	Zn
A	59.89%	0.04%	0.03%	Nil	Diff.
B	59.24	0.33	0.03	Nil	Diff.
C	59.57	0.85	0.02	Nil	Diff.
D	59.65	1.05	0.02	Nil	Diff.
E	59.73	1.76	0.02	Nil	Diff.

The brass "as received" was in the form of 1/2-inch extruded round rod. Typical structures of the extruded material are shown in photo-micrographs "A" (=alloy *A*) and "B" (= alloy *E*) of Fig. 3.

Brasses

Brasses are essentially alloys of copper and zinc though they may contain, for special purposes, other elements in small amounts. Copper and zinc alloy in all proportions, but only the alloys above 50 percent copper, are important as engineering materials. Many of these bear special or trade names as, for example, the particular composition of concern here—the 60/40 alloy—which is known as Muntz Metal.

The high copper brasses resemble copper in many respects, being strong, tough and ductile, and capable of being worked in the cold. The compositions of medium copper content as Muntz Metal are still stronger but less ductile at ordinary temperatures. Their low ductility effectively limits the amount of cold deformation that may be given them; they may, however, be worked hot.

Structural Composition of the Industrial Brasses

The industrially important copper-zinc alloys fall structurally into two groups: (1) those containing upward of 61 percent copper, and (2) those containing less than this amount but more than 50 percent. Brasses of the first group consist of a single solid solution, designated the alpha solution. The alloys of this group are commonly called alpha brasses.

The alpha solid solution exhibits the usual features associated with the solid solution type of metallographic structure,

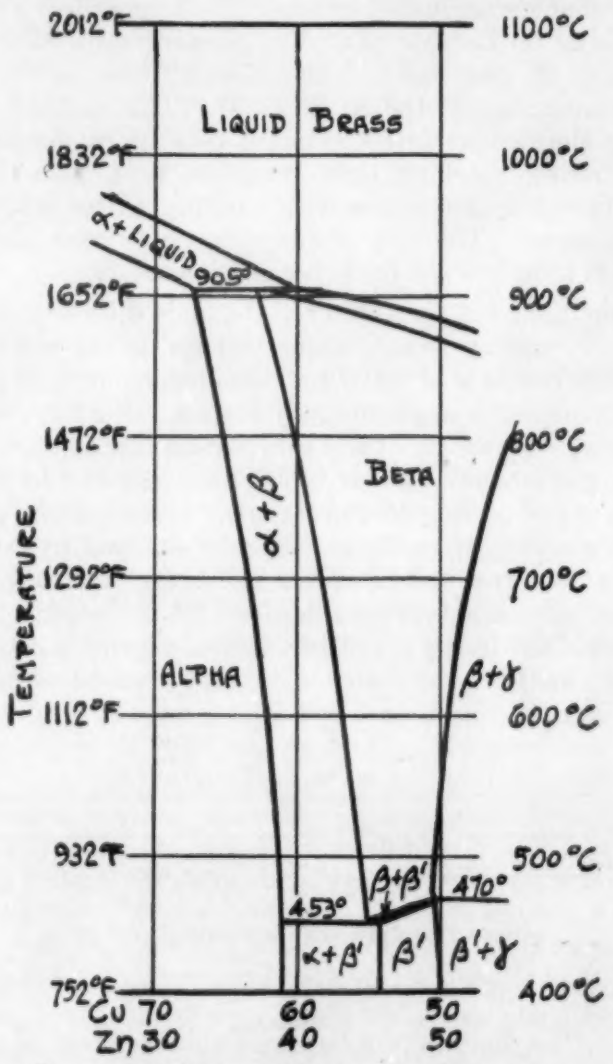


Fig. 1—Part of Copper-Zinc Equilibrium Diagram

viz., a marked dendritically segregated (cored) structure in the cast condition and homogeneous equi-axed polyhedra in the completely homogenized (annealed) alloy. Twinning is profuse in strained alpha that is subsequently annealed.

Brasses of the second group possess, in general, a duplex structure. Exceptions are those compositions at the extreme end of the range, with from about 50 to 54.5 percent copper, which, like the high copper brasses of the first group, consist of a single constituent. Alloys in the bi-phase range, that is, from 54.5 to 60 percent copper (including the particular composition under consideration here), consist of the alpha solid solution as described above and, in addition, a second quite distinct solid solution, beta. The low copper alloys noted as exceptions to the general rule of structural duplexity of alloys of this group consist solely of this beta solution. Like the alpha brasses these beta brasses freeze selectively, forming a cored structure in the ingot, while possessing in the completely diffused condition a homogeneous, polyhedral granular structure. Beta brasses, however, do not form annealing twins.

[1] Submitted as a partial fulfillment for the degree of Master of Science in Metallurgical Engineering at the College of Engineering of the Carnegie Institute of Technology. Published by permission of the Director of the College.

[2] Assistant Professor of Metallurgy, The Carnegie Institute of Technology, Eveleth Scholar (1929–30), Harvard University.

[3] F. Osterman, *Zeitschrift für Metallkunde*, May, 1928

The equilibrium diagram of the copper-zinc series covered by this article is given in Fig. 1.[4]

The Effect of Lead on the Physical Properties of Brass

Commercial brasses always contain small amounts of lead, the result of contamination from the spelter used in its manufacture.[5] According to Guillet,[6] who investigated the effects of lead and of other metals on brass, lead lowers the strength, the resistance to impact, and particularly the ductility of brass while affecting the hardness but slightly. Sperry[7] had previously reported the same findings for the effect on the strength and ductility. Carpenter[8] found that lead has no effect on the critical point in brasses containing the beta phase—a point checked by Parravano and his co-workers.[9] Carpenter[8] and the latter group of investigators interpret this non-influence on the critical points to mean that lead has no solubility in brass.

Lead is purposely added to the brasses in amounts up to 2 percent or above to increase machinability. The lead is insoluble in the brass—at least, it is insoluble in the alpha phase—and distributes itself as small spheroids in the boundaries surrounding the grains. This inter-crystalline segregation of the lead destroys the normal continuity of the crystalline aggregate, resulting in a decreased cohesion between the grains. To this rather than to the decreased strength may be ascribed the easy machinability of leaded brasses.

Outline of Procedure

Six different heat-treatments, given to alloys *A* to *E*, inclusive, are included in this investigation. Each heat-treatment is given a series number. Series I to III inclusive had, with the exception of the temperature variable, the same heat-treatment. In each of these three series, the brasses (1) were slowly heated to the desired temperature (and this was chosen so as to stand in some relation to the position of the alpha-beta solid solubility curve at the 60 percent copper isopleth); (2) were held at that temperature for a time sufficient for equilibrium to be attained; and (3) were then quickly quenched in an ice-water mixture. The purpose here was to study at room temperatures the relationships of the two phases holding at the quenching temperature, assumption being made, of course, that the cooling was sufficiently rapid to prevent any but an appreciable change from that existing at which the brass was quenched.

Series IV is concerned with the effect on the micro-structure of two widely different rates of cooling versus lead content. With this difference in the manner of cooling, the procedure followed in this series was that followed in the preceding three. In the next group of experiments (Series V) is studied the effect on the micro-structure of a double heat-treatment. In this series the alloys were first quenched from within the beta field, and then re-heated to temperatures which were below those used on the quench.

Series VI collects the results of some experiments made in an attempt to determine the distribution of the free lead as between the alpha and beta solutions.

Description of Apparatus Used

The furnace (Fig. 2) used was a small tube resistance furnace using 5 amperes at 220 volts. A rheostat in the circuit provided for the temperature control necessary, and was sufficiently effective after a little experience was gained in its operation, in maintaining a practically constant temperature in the furnace for the time interval required. The temperature of the specimen was measured by a carefully calibrated platinum/platinum-rhodium thermocouple, and a suspension type galvanometer (millivoltmeter). The couple was encased in a porcelain sleeve, open at the hot junction end to permit the insertion of the bare junction into the specimen. The specimen was $^1/_2$ inch long by $^1/_2$ inch in diameter, had a hole drilled to the center to receive the bared end of the thermocouple, and was supported by a nickel wire frame in the center of the furnace.

Experimental Results

The effect of varying amounts of lead on the alpha-beta solubility relationships is revealed in the micro-structures of the several brasses after heat-treatment according to one of the procedures mentioned. The photomicrographs of the different micro-structures are given in Figs. 3 to 5. The detailed heat-treatment given each series and a brief discussion of the results follow:

Series I. Each alloy in this series was heated to 750° C., held exactly at that temperature for one-half hour, and then quickly quenched in ice-water. Microscopic examination of each of the five brasses given this treatment showed residual (i. e., undissolved) alpha. Photomicrographs "C" and "D" of Fig. 3 give the structure of the low-lead brass (alloy *A*) and

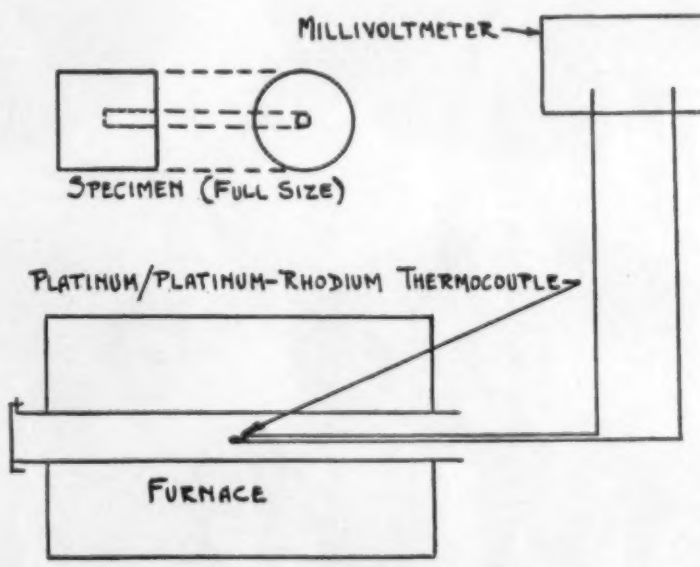


Fig. 2—Furnace and Specimen

of the brass of maximum lead content (alloy *E*), respectively, after this treatment. The presence of free alpha is to be expected in all cases since the temperature to which the brasses were heated and from which quenching was done is just below where the alpha is completely absorbed. It is evident that lead confers no increased solvent powers on the beta solution; as a matter of fact, the solubility of alpha in beta is decreased since those alloys of 0.33 percent lead and above have considerably more of the alpha phase than alloy *A* with negligible lead.

The effect of the time factor on the solution of the alpha at 750° C., if anything, is inconsequential. The micro-structure of alloy *A* after one hour's heating at 750° C. showed as much residual alpha as did the one of one-half hour's heating.

The grain size is affected by the presence of lead, the brasses containing appreciable amounts of lead having generally smaller grains than alloy *A*. This is, of course, an example of simple mechanical obstruction to grain growth.

Series II. In this series, as in the preceding, the five alloys were heated to and carefully maintained at the desired temperature—in this case, 800° C.—for one-half hour and then quenched in ice-water. According to the equilibrium diagram (Fig. 1), 800° C. is the temperature immediately above where the alpha is completely absorbed on heating. Regular brasses

[4] A. S. S. T. Handbook (1929 Ed.). Reproduced by permission.
[5] Hoyt, "Metallography," vol. II, page 111 (McGraw-Hill).
[6] Guillet, *Compt. Rend.*, **140**, 307 (1905); **142**, 1047 (1906); *Rev. de Met.*, **2**, 97 (1905); **3**, 159 (1906).
[7] Sperry, *Trans. A.I.M.E.*, **27**, 485 (1897).
[8] Carpenter, *Jour. Inst. of Metals*, **8**, No. 2, 51 (1912).
[9] Parravano, Mazzetti and Moretti, *Gazz. Chim. Ital.*, **44**, 251 (1912).

quenched from this temperature should show, then, no undissolved alpha.

The structure of the end alloys of the series (viz., alloys *A* and *E*) given this treatment is shown in "E" and "F" of Fig. 3. Photomicrograph "E" is the structure of the 0.04 percent lead alloy, and the structure consists of homogeneous beta grains with a narrow feathery fringe of alpha. This alpha in the boundaries of the beta polyhedra is that precipitated on cooling despite the rapidity of the cooling rate as produced in an ice-water quench. There is, however, no undissolved alpha, and thus the structure is in accord with the phase diagram that the beta solution alone is stable above 775° C.

Photomicrograph "F" (Fig. 3) gives the structure of the 1.76 percent lead-brass after the one-half hour's treatment at 800° C., followed by quenching. It is typical of the other leaded alloys after this treatment. Considerable residual alpha is present. Moreover, the amount of this phase precipitated on quenching, as measured by the depth of the intercrystalline fringe, is much greater than in alloy *A*.

The grain size, as usual, is smaller in the leaded alloys than in the one (alloy *A*) practically free from lead.

Series III. Each of the five brasses in this series was heat-treated as in the two preceding series with the exception that the quenching temperature used here was 850° C. This temperature is well above that where the alpha solution normally is completely dissolved on heating. Typical structures of the alloys quenched from 850° C. are shown in photomicrographs "G," "H" and "I" of Fig. 3. Photomicrograph "G" gives the structure of the 0.04 percent lead-brass (= alloy *A*). The structure is identical with that as shown in photomicrograph "A" (of Fig. 3). It consists of homogeneous beta crystallites with only a trace of the alpha phase in the boundaries, again

Fig. 3—Photo. A, Alloy *A*, Extruded. Photo. B, Alloy *E*, Extruded. Photo. C, Alloy *A*, Quenched from 750° C. Photo. D, Alloy *E*, Quenched from 750° C. Photo. E, Alloy *A*, Quenched from 800° C. Photo. F, Alloy *E*, Quenched from 800° C. Photo. G, Alloy *A*, Quenched from 850° C. Photo. H, Alloy *D*, Quenched from 850° C. Photo. I, Alloy *E*, Quenched from 850° C. Magnification = 300× (Reduced Slightly). Etchant = $NH_4OH + H_2O_2$.

the result of a slight precipitation during cooling. As in the case of the corresponding alloy of the preceding series, the exclusive beta structure could have been predicted from the phase diagram.

The remaining alloys of the group, with the exception of the one highest in lead, alloy *E*, show likewise no residual alpha (see, for example, photomicrograph "H" which gives the structure of alloy *D* with 1.05 percent lead), though they all, including alloy *E*, show an alpha marginal deposition of varying but of considerable depth. Here, as in the preceding series, the amount of the alpha solution separating at the boundaries on quenching as indicated by the fringe depth is much greater in the four high-lead alloys than in alloy *A* with only 0.04 percent lead.

Alloy *E* (see photomicrograph "I," Fig. 3) shows, after one-half hour's heating at 75° C. above the normal solubility limit of the alpha solution, still an occasional crystallite of undissolved alpha.

Series IV. In this series, two specimens of the low-lead alloy (alloy *A*) and two of alloy *E* with 1.76 percent lead were heated to 850° C. for one-half hour; one sample of each brass was then cooled in air and the other was permitted to cool with the furnace. The structures of the two air-cooled specimens are those shown in photomicrographs "A" and "B" of Fig. 4. (A is the structure of the 0.04 percent lead-brass and B that of the 1.76 percent lead). A comparison of these two photomicrographs shows (1) a difference in the size of the lens-shaped alpha "areas," these being the smaller in the brass of higher lead content, and (2) relatively less of the beta matrix in the higher lead alloy.

In the furnace-cooled alloys (see "C" and "D" of Fig. 4), difference in grain size is again noticeable, and any difference

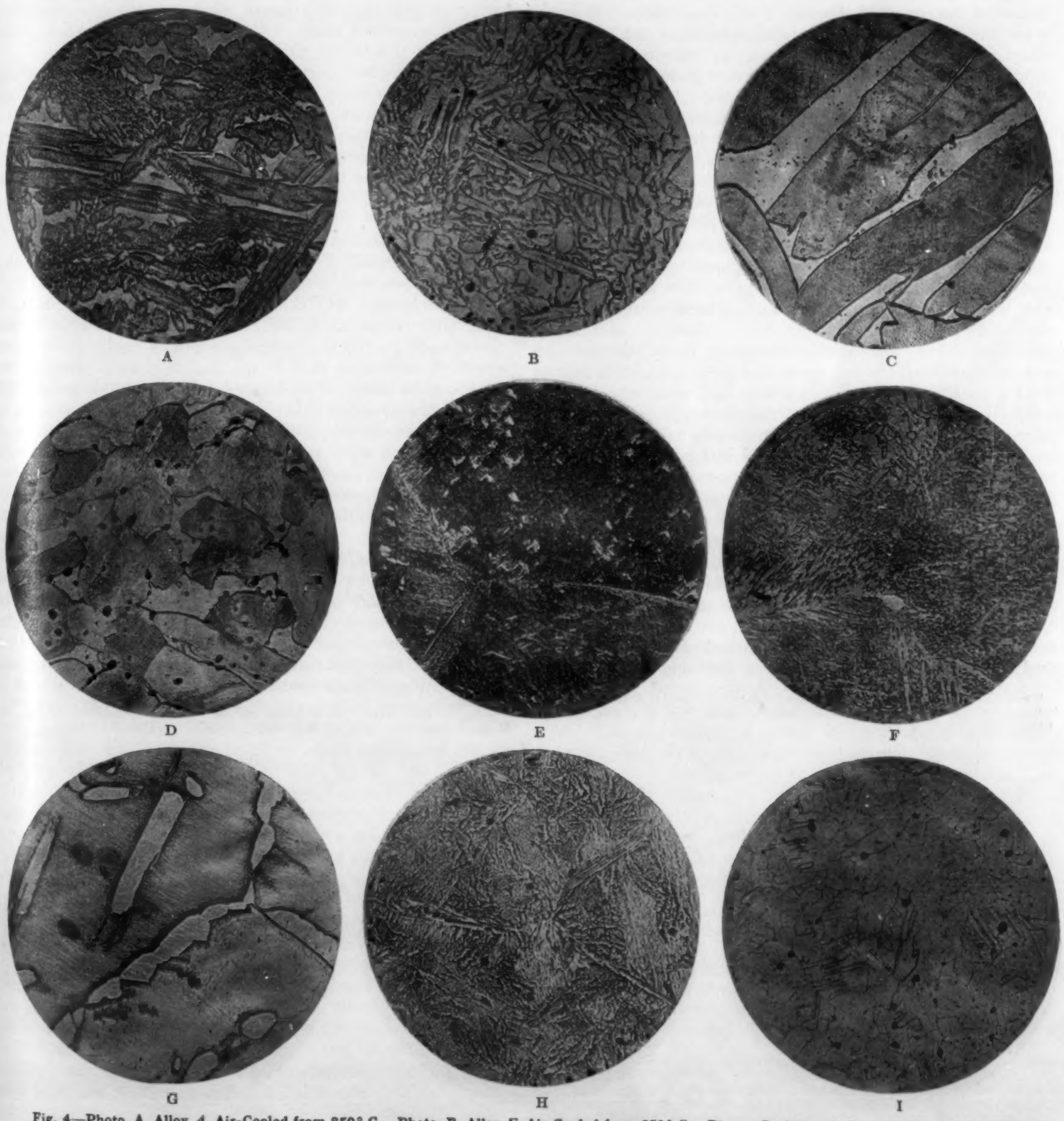


Fig. 4—Photo. A, Alloy *A*, Air-Cooled from 850° C. Photo. B, Alloy *E*, Air-Cooled from 850° C. Photo. C, Alloy *A*, Furnace-Cooled from 850° C. Photo. D, Alloy *E*, Furnace-Cooled from 850° C. Photo. E, Alloy *A*, Quenched and Re-Heated to 250° C. Photo. F, Same, Quenched and Re-Heated to 500° C. Photo. G, Same, Quenched and Re-Heated to 750° C. Photo. H, Alloy *E*, Quenched and Re-Heated to 250° C. Photo. I, Same, Quenched and Re-Heated to 500° C. Magnification = 300× (Reduced Slightly). Etchant = $NH_4OH + H_2O_2$.

in relative amounts of the two phases, while not marked, is again in the direction of less beta in the high-lead alloy.

Series V. A double heat-treatment was given the brasses in this series. This consisted of (1) quenching the different alloys from above 800° C., that is, from the beta field, and (2) re-heating the quenched brasses to three different temperatures, viz., 250, 500 and 750° C. This double treatment was confined, as in the immediately preceding series, to the extreme lead composition, that is, to the 0.04 percent lead alloy and to the 1.76 percent lead. Photomicrographs "E," "F" and "G" of Fig. 4 give the structures of the low-lead brass after the double treatments, while "H" and "I" of Fig. 4, and "A" of Fig. 5 give those of the 1.76 percent lead-brass.

We have seen that brasses of this composition (60 percent copper), which have been slowly cooled from 800° C. or above, have duplex structures and consist, at room temperatures, of two phases, both solid solutions—alpha and beta. An examination of the structure of such a slowly cooled brass will reveal what the "lever relationship rule" applied to the phase diagram indicates, namely, that the alpha constituent is, under equilibrium conditions, the phase present in the larger amount. We have also seen that on heating this duplex alloy, the preponderant alpha solution is gradually absorbed by the beta, and at about 775° C., in the absence of disturbing factors, its absorption becomes complete. The alloy, then, above 775° C. consists solely of the beta constituent. On slowly cooling from 775+° C., the reverse changes from those taking place on heating occur, that is, slightly below 775° C. the alpha constituent reappears as a decomposition product of, or a precipitate from the beta solution; increases in amount as the temperature falls and at room temperatures becomes again the predominant phase. On the other hand extremely rapid cooling from 775+° C., as by a drastic quench, results in the retention of the beta solution practically intact, the only decomposition being a slight one at the grain boundaries and resulting in the rejection of a small and ordinarily inconsequential amount of alpha. But while the rapidly cooled alloy consists practically entirely of the beta solution, it is obviously an unstable solution since it is supersaturated. It tends to reject alpha (or more accurately, copper as the copper-rich alpha solution), but actual rejection is prevented at ordinary temperatures because of the rigidity of the alloy lattice. This disposition of the supersaturated beta solution to reject the extraneous solute becomes an actuality if, in any way, a greater freedom of molecular movement is conferred on the metastable solution as, for example, by deforming the alloy in the cold,[10] or by the application of heat. The latter method was the one used. Re-heating the quenched alloy even to relatively low temperatures results in a lessening of the lattice rigidity, sufficient to permit of the molecular migration necessary to the precipitation of the excess solute. Unlike the rejection of the alpha unavoidably occurring to a small extent in the grain boundaries on quenching the precipitation on the re-heating is not so localized but takes place largely within the several grains.

The micro-structures of the low-lead alloy (alloy *A* with 0.04 percent Pb) after quenching from 775+° C. and subsequently re-heated to 250, 500 and 750° C. are shown in Fig. 4 (photomicrographs "E," "F" and "G"). The effect of the temperature of re-heating on the completeness of the break-down of the metastable solution is evident. The structure of the brass re-heated to 250° C., as is shown in photomicrograph "E," is quite indistinct and reminds one of the structure of certain heat-treated alloy steels. The quenched brass re-heated to 500° C., whose micro-structure is given in photomicrograph "F," has a more defined structure. There are irregularly shaped areas of what one can now definitely say is a separating phase, with an occasional indication (twinning) that this is the alpha solution.

In the quenched specimen re-heated to 750° C. occur alpha crystallites, generally (on a plane section) oblong in shape with some almost rectangular. In addition, considerable alpha is now present in the grain boundaries. In this alloy precipitation is complete; as a matter of fact, re-solution back into the beta has begun. The re-solution mechanism is peculiar, and has been previously reported upon by the present author.[11]

In Fig. 4 (photomicrographs "H," and "I") and in Fig. 5 (photomicrograph "A") are given the structures of the high lead (1.76 percent) brass after the same double treatment. Photomicrograph "H" shows the structure of the quenched alloy after re-heating to 250° C. It has, in contrast to the corresponding alloy of low-lead content, a fairly well-defined structure, indicating that in the leaded brasses precipitation of the excess solute is accelerated. In photomicrograph "I," we have the structure of the high-lead brass after re-heating to 500° C. Very definite twinned crystallites of alpha are present, showing a more advanced stage in the rejection of the alpha and in the establishment of equilibrium than in the low-lead alloy with a corresponding treatment.

The structure of the high-lead brass after re-heating to 750° C. (photomicrograph "A," Fig. 5) resembles, in a general way, the correspondingly treated 0.04 percent Pb brass. The grain size is smaller as are all the brasses carrying an appreciable lead content, and there is more of the alpha constituent present than in the preceding low-lead alloy.

From this series one sees the effect of lead in accelerating the precipitation of the alpha phase from the supersaturated beta solution. In the preceding series, where the effect of

[10] See G. D. Bengough's discussion of Johnson's "Some Features in the Behavior of Beta Brass When Cold Rolled," *Jour. Inst. of Metals*, **25**, 311 1920).

[11] L. R. van Wert, "Some Observations in Heat Treatment of Munts Metal," *Am. Inst. Min. & Met. Engr., Tech. Pub.* **180**, 7 (1929).

A B C

Fig. 5—Photo. A, Alloy *E*, Quenched and Re-Heated to 750° C. Photo. B, Alloy *E*, Slowly Cooled from 775+° C. Photo. C, Same, Slowly Cooled from 775+° C. Magnification = 300× (Photo. B = 100×) (Reduced Slightly). Etchant = $NH_4OH + H_2O_2$.

lead was seen to retard the solution of the alpha into the beta, the effect here of hastening dissolution was not unexpected.

Conclusions

The presence of lead in brasses of the Muntz Metal type in amounts above 0.04 percent disturbs the normal equilibrium of the co-existing alpha and beta phases in the direction of increasing the relative proportion of the former solution which effect amounts to a decrease in the solubility of the alpha in the beta. This decreased solubility is believed to be shown:

1. By the higher temperatures necessary for the complete solution of the alpha on heating.
2. In the greater difficulty of retaining the alpha in solid solution in the beta on rapid cooling.
3. In the less stable condition of the supersaturated beta solution in which lead is present when this solution is re-heated to low temperatures.
4. By the comparatively larger amounts of the alpha constituent in slowly cooled alloys containing lead than in similarly treated alloys low in lead.

Theoretical Considerations

It does not seem difficult to explain this effect of lead on the phase relationships of the alpha and beta solutions. Guillet in his work on the effect of third metals previously mentioned indicated that other metals have the same effect in brass as zinc, and differ from that of zinc in degree only. He arrived at a formula showing the amount of the third metal equivalent metallographically to 1 percent zinc:

$$A' = A/100 + \text{as } q(t - 1)$$

in which A is the percent copper in the brass, A' is the apparent percentage as deduced by the micro-structure, q the percentage of the third metal and t the percentage of the third metal which is equivalent metallographically to one percent zinc. Guillet found that this relationship applied to all alloys with a copper content from 55 to 63 percent provided that no new phase made its appearance on the addition of the third metal. The value of t for lead from this formula was one (1), that is, lead is equivalent metallographically to zinc. On the other hand, Carpenter, Parravano and others report that lead has no effect on the critical point in brass (apparently the change at 453–470° C.), and conclude that the lead remains undissolved. Obviously, this conclusion precludes the application of Guillet's rule since a new phase, the free lead, appears. The results of the present investigation seem to indicate that both Carpenter *et al.* and Guillet may be partly in error, the former in assuming complete insolubility of the lead, and Guillet in assigning to dissolved lead an effect qualitatively and quantitatively similar to that of zinc.

There seems to be no doubt that lead does, to some extent, dissolve in the high-zinc brasses, particularly in those heat-treated brasses in which beta becomes the predominant phase. An examination of the micro-structure of the high lead alloys shows, without doubt, less free lead than one would expect if no lead were soluble. Yet according to Guillet's findings this dissolved lead is metallographically equivalent to zinc and should lower the temperature (as zinc does) where the alpha solution is completely dissolved by the beta on heating, since the alpha-beta solid solubility curve drops sharply with increasing zinc content. As the results of the present study show—if the author interprets them correctly—the opposite is the case, and lead actually raises the temperature where alpha ceases to be a structural constituent. Thus lead acts not with but opposed to the zinc.

A possible explanation of the observed effect of lead in raising the temperature-composition curve marking the boundary between the alpha and the alpha-beta fields is given:

1. The commonly accepted facts of the nature of the metallographical constituents involved are: (*a*) that the alpha constituent is a solid solution of copper and zinc in which copper is the solvent. This solid solution has the face-centered cubic lattice of copper, and like copper has no appreciable solubility for lead; (*b*) that the beta constituent is likewise a solid solution, considered most probably of copper in an intermetallic compound, CuZn. The lattice of this solution, like that of its compound-solvent, is body-centered cubic.

2. The author ventures the opinion that the beta solution, or more properly its solvent, CuZn, has some solubility for lead, that is, in brasses where the beta solution and lead are both present, some part of the latter is in solution in the former. In fact, Carpenter in the reference previously mentioned[12] shows a photomicrograph of a homogeneous leaded brass having a composition of 51+ percent copper, 45.9 percent zinc and 3.25 percent lead, in which no structurally free lead is visible, and one is compelled to accept the alternative possibility that the lead is in solution. Many of the beta "areas" of the quenched brasses made in this present study are quite free from lead, as, for example, the brass shown in photomicrograph of Fig. 3.

Another structural feature exhibited by the high-lead, slowly cooled brasses which might indicate some solubility of the lead in the beta solution is shown in the alloys whose micro-structures are given in Fig. 5, "B" and "C." The brass whose structure is shown in these three photomicrographs is the one containing 1.76 percent lead. In these photomicrographs ("B" and "C") one sees that the lead spheroids are practically all within the alpha "areas." The explanation of this apparently favored location is probably as follows: At temperatures above 775° C. (the brasses were slowly cooled from 775+° C.), the lead was completely dissolved in the beta constituent, the only copper-zinc phase present at these temperatures. On slow cooling through 775° C., the alpha solution in which the lead is not soluble began to separate and continued to do so down to some much lower temperature. This beta→alpha transformation starts from several nuclei within the various beta crystallites, and continues with drop in temperature through further decomposition of the beta solution with a gradual enlargement of the original nuclear masses into sizable alpha crystallites. As the latter grow within the beta matrix through the gradual accumulation of face-centered material on their surfaces, the lead, whose rejection from solid solution is simultaneous with the beta to alpha change, separates at the interface of the two solutions. The precipitated lead is molten, at least it is above 625° C. above where most of the alpha forms, and, through the action of surface tension, it coalesces into spheroids at the contact surfaces of the two phases, though usually lying actually within the alpha "areas."

3. The dissolved lead in the beta solution acts in respect to the alpha-beta equilibrium in the same manner as does copper, viz., it raises the temperature at which the alpha phase is completely dissolved;[13] it renders more difficult the retention of the beta solution intact when the same is quenched from above 775° C., and makes the supersaturated solution so produced less stable, as evidenced by the precipitation of the alpha earlier and more completely on a re-heating.

Acknowledgments

Acknowledgments are due to the Bridgeport Brass Co., Bridgeport, Connecticut, who made the brasses specially for this study, and particularly to Mr. John L. Christie, metallurgist for his interest and help.

[12] Carpenter, *Jour. Inst. of Metals*, **8**, No. 2 (1912), (Plate XV, No. 5, insert between pages 72–73).

[13] Since this study was completed, there has appeared an excellent paper in *Zeitschrift für Metallkunde* (June, 1929), "Der Einfluss von Dritten Metallen auf die Konstitution der Messinglegierungen: I. Der Einfluss von Blei" by Bauer and Hansen in which these investigations report results that confirm this effect of lead on the elevation of the $(\alpha + \beta)/\beta$ solid solubility curve. See, in particular, Figure 12 and text, page 191.

X-Ray Metallography in 1929*

By George L. Clark[1]

9. The X-Ray Analysis of Fabrication of Metals and Alloys

1. Fiber Diagrams. It is now a familiar fact that metal powders or random aggregates yield pinhole diffraction patterns on flat photographic films consisting of concentric uniformly intense rings. Whenever a piece of drawn wire or thin rolled foil are used as specimens, perpendicular to the primary beam, the diffraction rings are very intense in localized intensity maxima as though many more crystal grains are contributing reflection effects in certain directions, while in other positions few, if any, crystal grains are available for reflection, and there is little or no blackening on the film. Thus the rings observed for random arrangement of grains become series of symmetrical segments in the case of directed or preferred orientation. This type of pattern for worked metals, generally designated fiber diagrams, has been illustrated in Figure 24, Part II, for aluminum wire, and Figure 62, Part IV, for aluminum sheet. Figure 75 is the pattern for steel wire.

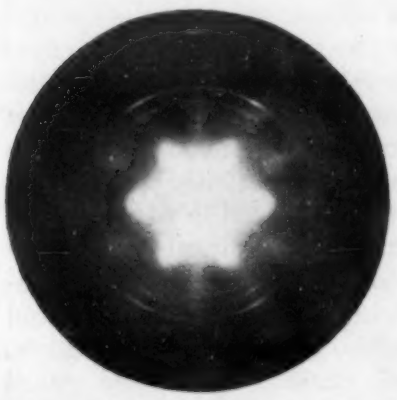


Figure 75—Fiber Pattern for Hard Drawn Steel Wire

Drawn wires and rolled sheets represent different types of preferred orientation. In wires the same pattern is obtained with any orientation so long as the X-ray beam passes perpendicular to the wire axis, while in rolled sheets differently appearing fiber patterns are obtained with the beam perpendicular or parallel to the rolling plane.

These are fiber structures in the same sense that cellulose, stretched rubber or asbestos are fibers. None of these materials is a single crystal; all are built up of many crystal grains, but these are arranged so that a definite crystallographic axis is parallel to the axis of the fiber. In an aluminum wire which has not been annealed after drawing, the X-ray pattern demonstrates that the body diagonals, or [111] direction, in all the grains, each of which is a single crystal built up from unit face-centered cubes, lie parallel to the wire axis. Evidently, therefore, this common orientation has been induced in the process of mechanical working; the particular position is evidently that which will present maximum resistance to further deformation. It will be noted that no other limitation has been put on preferred orientation in an aluminum wire, for example, than that the [111] direction is parallel to the wire axis, or direction of drawing. Hence any grain may be turned anywhere through 360° around a body diagonal as an axis and still fulfill conditions, and thus the outer form of grains in the wire may appear perfectly irregular with any kind of a face in the surface. Herein lies the difference in the orientation of grains in a rolled sheet or foil, for in this case a definite crystallographic direction lies parallel to the direction of rolling *and, also,* a definite crystallographic plane in all the crystal grains lies parallel to the plane of rolling. For example, in strongly rolled iron or steel a *face* diagonal [110] direction lies parallel to the direction of rolling, and a cube face parallel to the plane of rolling. On account of this added limitation in rolled structure which does not apply in drawn wires or complete fiber structure, this is called limited fiber structure.

In the foregoing discussion ideal cases of exact arrangements have been implied. In practice these cases are never realized since the orientations are never perfect, though the greater the deforming force the more nearly do the grain positions approach the ideal. As will become apparent, it is possible to determine from the X-ray patterns the departures from limiting ideal orientations.

As previously explained, the Laue or monochromatic pinhole method is almost exclusively used in the study of worked metals since it affords a pattern 360° in azimuth. It is necessary only to mount a wire or sheet specimen over the outer pinhole so that the beam will pass perpendicular to the wire axis or rolling direction. The pattern is registered on a flat photographic film.

2. The Interpretation of Complete Fiber Patterns (Drawn Wires). Of first concern is the pattern of the Debye-Scherrer rings which defines the particular metal. All the lattice planes with the same lattice spacing d, reflect rays on the same diffraction ring, which is continuous in the case of random orientation or segmented into spots or arcs for fibered materials. It is useful to list for the body-centered and face-centered cubic lattices the planar indices corresponding to the rings which appear, passing from the innermost outward.

Body-Centered Cubic		Face-Centered Cubic	
Indices	$\frac{a_0}{d_{hkl}} = \sqrt{h^2+k^2+l^2}$	Indices	$\frac{a_0}{d_{hkl}} = \sqrt{h^2+k^2+l^2}$
(110)	1.41	(111)	1.23
(200)	2.00	(200)	2.00
(112)	2.45	(220)	2.83
(220)	2.83	(113)	3.32
(130)	3.16	(222)	3.46
(222)	3.46	(400)	4.00

In this fashion it is possible to determine the planar indices for each ring.

Next to be found are the positions of the intensity maxima upon the rings. One of the sets of parallel reflecting planes may be imagined rotated 360° around an axis perpendicular to the primary X-ray beam. In the course of this rotation it will pass four times through the proper angle for reflection in accordance with Bragg's Law, and produce upon a photographic plate placed behind the specimen a four-point pattern which is symmetrical with respect to a vertical line on the plate parallel to the rotation or fiber axis, and also with respect to a horizontal line. In other words these maxima are, for example, at the clock hour hand positions of 1:30, 4:30, 7:30 and 10:30. See Figure 76. If this particular reflecting plane in a special case is parallel to the axis of rotation (or fiber axis) then only two spots are produced on the ring on the horizontal line (3 and 9 o'clock). No reflection occurs, of course, if this plane is exactly perpendicular to the rotation axis. Two spots occur on the vertical line (12 and 6 o'clock) if the angle of the reflecting plane with respect to the rotation (fiber) axis is equal to the angle of incidence of the X-ray beam. It is at once clear, therefore, that the positions of intensity maxima on a given ring on the photographic plate may be measured and used directly to deduce the positions of lattice planes in the wire in a very simple manner. If a is

* Concluding part of an article in five parts: for Part I see pages 14–17 of this publication, July; Part II, pages 57–68, August; Part III, pages 98–111, September; Part IV, pages 153–161, October.

[1] Professor of Chemistry, University of Illinois.

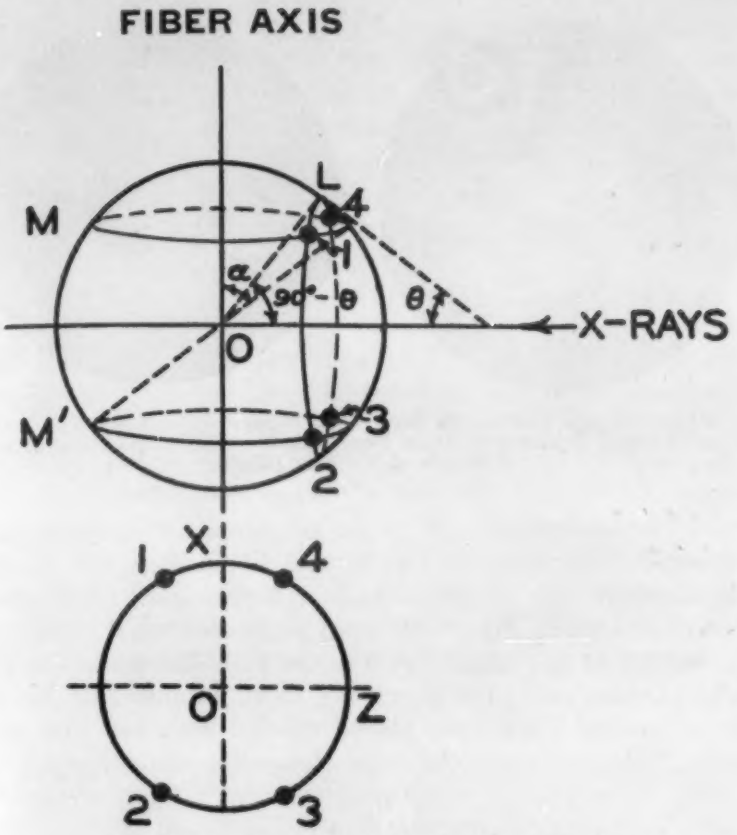


Figure 76—Ideal Four-Point Diagram for Fiber

the angle between the normal to the set of reflecting planes and the rotation (fiber) axis, and δ is the angle measured on the film between a radius drawn through a particular intensity maximum and the vertical line (which is known to be parallel to the rotation or fiber axis) then

$$\cos \delta = \cos \alpha / \cos \theta$$

where θ is the angle of incidence. At small reflection angles such as are true for the most important diffraction circles for metals $\cos \theta$ is approximately 1. Hence $\delta = \alpha$. Thus a simple angle measurement on the film is also the value for the angle between the normal to a set of reflecting planes and the fiber axis.

In any cubic lattice the angle between the fiber axis with indices *uvw* and a lattice plane *hkl* is given by

$$\cos \alpha = \frac{uh + vk + lw}{\sqrt{u^2 + v^2 + w^2}\ \sqrt{h^2 + k^2 + l^2}}.$$

In aluminum wire the [111] direction is the fiber axis. The innermost ring registers the reflection from all the octahedral planes, (111), ($\bar{1}$11), (1$\bar{1}$1), (11$\bar{1}$) and the other four parallel to these. Hence α, and consequently δ, on the film will be 0° for (111), which means that the (111) planes are perpendicular to the fiber axis [111] (as by definition), and cannot reflect. For the others $\alpha = 71° = \delta$. See Figure 77.

Further data for aluminum wire calculated in this way are:

Ring No.	Planes	Nc Cooperating	α
1(111)	($\bar{1}$11)	6	71°
5(222)	(1$\bar{1}$1)		
	(11$\bar{1}$)		
2(200)	(100)	6	55
6(400)	(010)		
	(001)		
3(220)	(110)	6	35
	(101)		
	(011)		
	($\bar{1}$10)	6	90
	($\bar{1}$01)		
	(0$\bar{1}$1)		
4(113)	113, etc.	6	30
	$\bar{1}$13, etc.	12	59
	11$\bar{3}$, etc.	6	80

Since there is agreement between the calculated positions and those found experimentally for drawn aluminum (Figure 24), the assumption of the [111] fiber axis is correct.

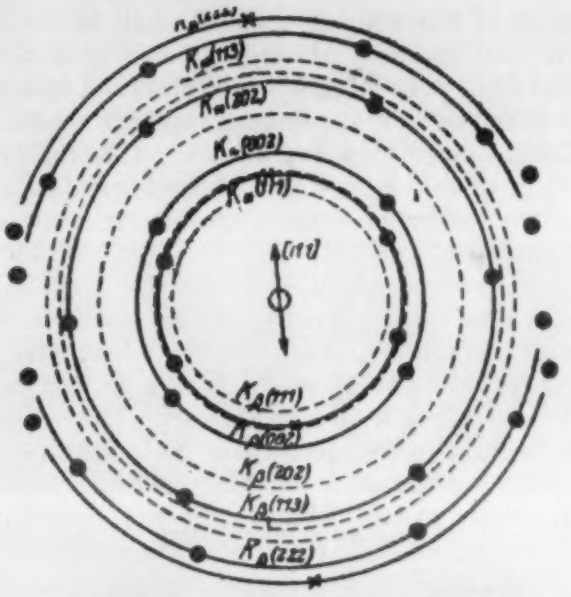


Figure 77—Theoretical Pattern for Wires with [III] Fiber Axis

For body-centered cubic wires like iron (Figure 75) the assumption may be made that the [110] direction is parallel to the wire axis and this is then tested.

Ring	Planes	No. Co-operating	α
1(110)	(101)	8	60°
4(220)	(10$\bar{1}$)		
	(011)		
	(01$\bar{1}$)		
2(200)	(100)	4	45
	(010)		
	(001)	2	90
3(112)	(211), (121), etc.	8	30
	(112), (11$\bar{2}$), etc.	4	55
	(2$\bar{1}$1), ($\bar{1}$21), etc.	8	73
	(1$\bar{1}$2), ($\bar{1}$12), etc.	4	90
5(130)	(130), (310), etc.	4	27
	(301), (031), etc.	4	48
	($\bar{1}$30), (3$\bar{1}$0), etc.	4	63
	(103), (013), etc.	12	77
6(222)	(111), (11$\bar{1}$)	4	35
	(1$\bar{1}$1), ($\bar{1}$11)	4	90

As a matter of fact the intensity maxima lying on the Debye-Scherrer rings are not sharp spots but are really arcs of 10° in cases of extreme cold work, or more (Figure 78). This means, of course, that all the crystal grains are not perfectly oriented and that there is a "scattering" in a cone around an average or ideal position which is the wire axis itself. The "scattering"

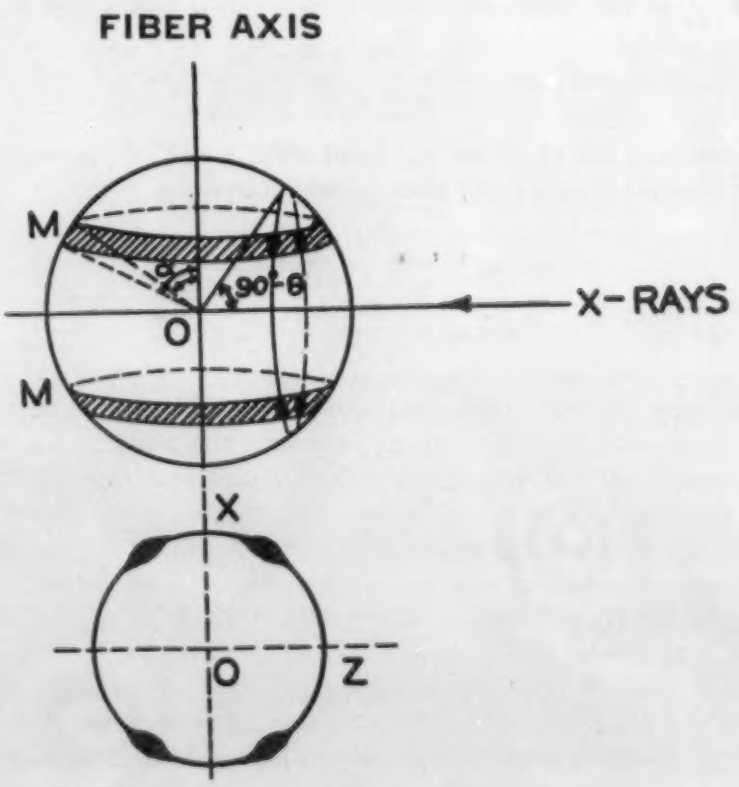


Figure 78—Actual Four-Point Diagram for Fiber

angle or apex of this cone is obviously half of the arc length of the intensity maxima. Every possible gradation of preferred orientation may be practically observed in metal specimens from sharp spots to continuous rings for random arrangement. The arc lengths of the maxima are, therefore, a measure of the amount of cold work and preferred orientation or fibering in a given specimen, either directly produced or residual after heat treatment.

In many cases of examination of fabricated metals it may be impossible or undesirable to orient the specimen with the fiber axis perpendicular to the primary X-ray beam. If, then, the specimen is placed at an oblique angle, a pattern is obtained with exactly the same Debye-Scherrer rings as before but the four-point diagram is changed when two of the points move apart on a ring and the other two together, still retaining symmetry with respect to vertical and horizontal lines on the film. Instead of one angle δ to be measured for the four spots, there are now two angles, δ_1 and δ_2, evaluated by

$$\cos \delta_2 = \frac{\cos \alpha - \cos \beta \sin \theta}{\sin \beta \cos \theta}$$

and

$$\cos \delta_2 = \frac{\cos \alpha - \cos (180° - \beta) \sin \theta}{\sin (180° - \beta) \cos \theta}$$

where α is the same as before, β is the angle between the fiber axis and the direction of the primary beam, and θ is the angle of incidence.

For evaluation of the indices of the fiber axis in a drawn metal, two or three methods are available:

a. Trial and failure method by assuming indices, calculating the intensity maxima to be expected on the various rings, as above illustrated for aluminum and iron, and comparing with experimental film.

b. Use of patterns for obliquely oriented fiber axis with a series of values for the angle β. If the crystal lattice plane perpendicular to the fiber axis (Polanyi's diatropic planes) reflect a beam of wave-length λ incident at the angle θ, then when $\beta = 90° - \theta$, an intensity maximum will appear at the 12 o'clock position on one of the Debye-Scherrer rings due to (*hkl*) planes. For cubic crystals the evaluation of the (*hkl*) indices for the ring upon which the intensity maximum appears gives at once [*hkl*] the fiber axis, since the normal to these planes is the same as the axis.

c. Sometimes only two or three intensity maxima are necessary to evaluate the fiber axis. Glocker and Kaupp[2] give the example of electrodeposited copper with maxima on the (111) and (200) (or (100), second order) rings. Since

$$\cos \alpha = \frac{uh + vk + lw}{\sqrt{u^2 + v^2 + w^2}\ \sqrt{h^2 + k^2 + l^2}}$$

where [*uvw*] is the fiber axis and (*hkl*) a set of planes, then for the (111) and (100) planes, respectively,

$$\cos \alpha_1 = \frac{u + v + w}{\sqrt{3}\ \sqrt{u^2 + v^2 + w^2}}$$

$$\cos \alpha_2 = \frac{u}{\sqrt{u^2 + v^2 + w^2}}.$$

Intensity maxima appear on both rings at 90°, hence $\delta_1 = \alpha_1 = \delta_2 = \alpha_2$; furthermore, substituting the values of $\cos \alpha_1$ and $\cos \alpha_2$, $0 = u + v + w$ and $0 = u$, or $v = -w$. The fiber axis is therefore $[0\bar{1}1]$.

X-ray patterns taken with the beam parallel to the fiber axis are characterized by one or two uniform Debye-Scherrer rings indicative of random orientation (Figure 79).

3. Multiple Fiber Structures in Drawn Wires. Sometimes more than one preferred orientation is observed as a multiple fiber structure. This is true of face-centered cubic metals in which both [111] and [100] directions serve as fiber

[2] *Z. Physik*, **24**, 121 (1924).

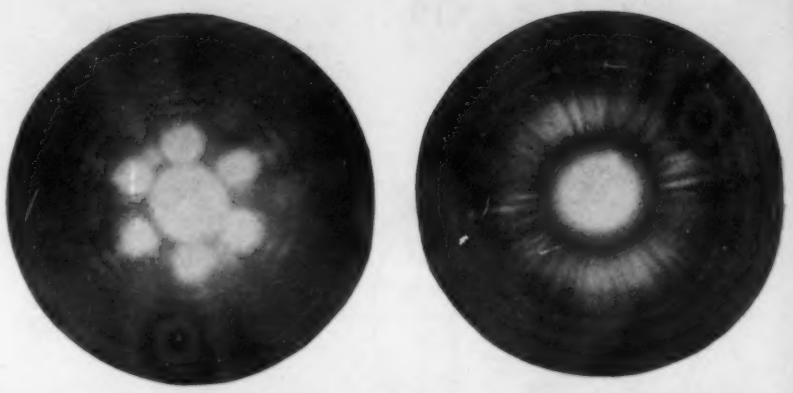


Figure 79—Patterns Illustrating Directional Properties for Same Specimen of Worked Copper, Taken with Beam Perpendicular (Left), and Parallel to the Direction of Working (Right)

axes. The distribution of grain orientations between these two varies depending on the metal. This has been studied quantitatively by Schmid and Wassermann.[3] Diffraction patterns shown in Figure 80 were registered on a cylindrical film instead of the usual flat film, so that the layer line diagrams characteristic for fibers are more prominently shown. The cylindrical films were placed coaxial with the wire as in Figure 80 and also coaxial with the beam in order to make possible the use of the microphotometer. The data obtained for the percentage of crystals in the [100] and [111] orientations and for the half length of interferences on the (200) ring as a measure of the exactness of fibering, are as follows:

Metal Wire	Percent Crystals with Parallel to Direction of Drawing [100]	[111]	Half Length of Interferences on (200) Ring [100]	[111]
Aluminum	0	100	...	3° 30′
Copper	40	60	7°	3°
Gold	50	50	8° 30′	4° 30
Silver	75	25	7° 30′	3°

The scattering around the [100] preferred orientation is evidently twice as great as around the [111] axis. The presence of a double fiber structure with varying proportions of each and variations in scattering around a fixed position have

[3] *Z. Physik*, **42**, 779 (1927).

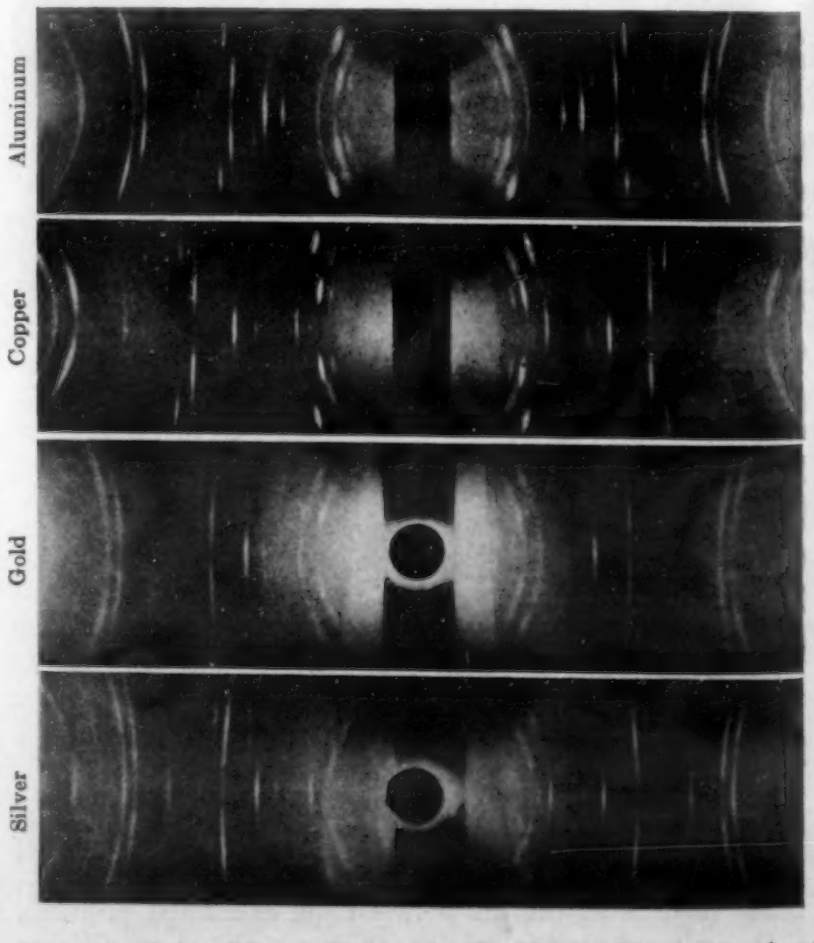
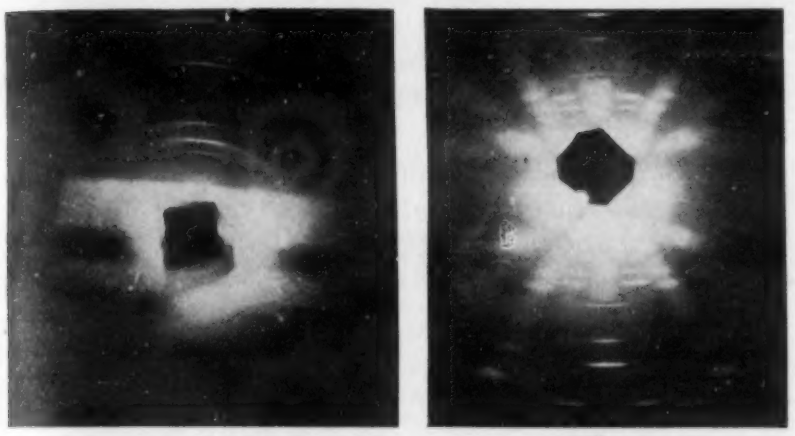


Figure 80—Debye Scherrer Patterns for Hard Drawn Wires (Schmid and Wassermann)

great practical significance in differentiating drawing, annealing and physical properties of aluminum, copper, gold and silver.

4. The Zonal Structures of Hard Drawn Wires. An interesting structural phenomenon in hard drawn wires is illustrated in Figures 81*a* and 81*b* for copper wire. A beam of monochromatic X-rays defined by a slit was reflected from the surface of a cold-drawn copper wire about 0.5 mm. in diameter. The pattern in Figure 81*a* shows a nearly random arrangement of grains in spite of the prediction concerning fibering. The wire was then etched down in successive steps and an X-ray examination made. Figure 81*b* shows the structure of the innermost core of the wire and it is characterized by extreme fibering. Hence, wires drawn through dies have distinctly zonal structures with the grains becoming more perfectly oriented the nearer to the wire axis considered as a line at the exact center. In other words, in the passage through the die, the flow of metal exactly in the direction of drawing occurs only in the middle of the wire, whereas in the walls the metal is flowing inward as well as along the length of the wire and the crystal grains are thus disposed at an angle to the core.



a b

Figure 81—Diffraction Patterns Illustrating Zonal Structure in Copper Wire, (a) Surface, (b) Innermost Core

Ordinary powder diffraction spectra (Hull method) also show the zonal structure. Figure 82*a* shows the pattern of the original copper wire, which is really the structure of the outer mantle of the wire. The intensities of the various diffraction lines are just about those to be expected from a somewhat random orientation. Figure 82*b* is the pattern for the core of this wire after etching down to a diameter of about 0.13 mm. A surprising change has occurred since the (111) line has entirely disappeared, the (200) line is about the same, the (220) line is about doubled in relative intensity, the (311) line is about half as intense, etc. This illustrates the error which might be made in the interpretation of such patterns if the facts were not known. The phenomena here observed agree with a [100] direction for the fiber axis but not so well with the [111]. Drier and Eddy[4] have made a similar study and related zonal structure with electrical conductivity.

[4] Am. Inst. Min. & Met. Eng. Preprint, Cleveland Meeting, 1929.

This condition of a central linear zone and a conical mantle of course is of primary importance in affecting the texture of the wire, and in the proper interpretation of diffraction patterns. The zonal structure of wires has also been studied by Schmid and Wassermann.[5] In Figure 83 are reproduced pat-

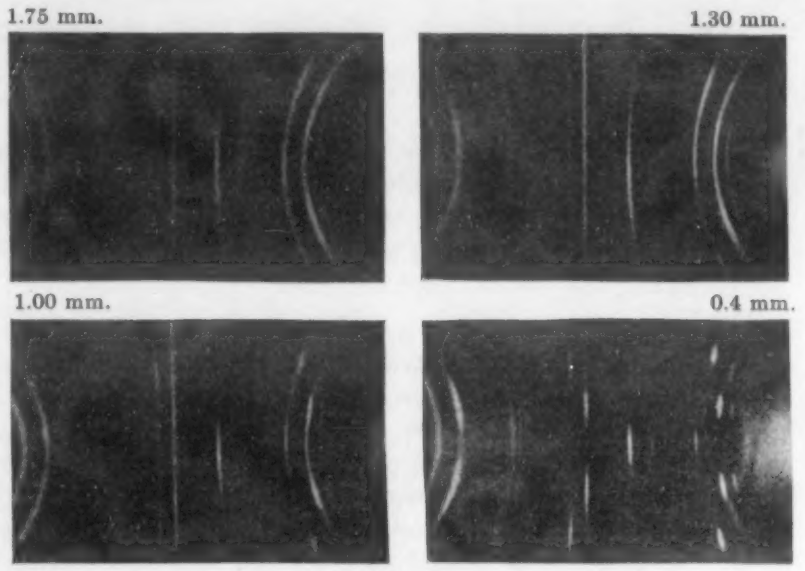


Figure 83—Patterns for Copper Wire Showing Zonal Texture with Decreasing Diameter (Schmid and Wassermann)

terns from their work on copper wire with the diameters 1.75, 1.3, 1.0 and 0.4 mm. Not only does the sharpness of fibering shown by the shorter interference maxima increase as layers are removed, but there is also evidence of unsymmetrical interferences. From these the inclination of the fiber axis [111] to the wire axis in different zones is determined as follows:

Distance of Layer from Center, Mm.	Inclination Angle
1.75 (outer skin)	<2°
1.6	9
1.3	6
0.9	4
0.4	0

This indicates that in the outermost skin of the wire, the effect of the die has been to keep the grains which are oriented nearly parallel to the direction of drawing, but slightly below this the conical flow is evident. The texture of a hard drawn wire, therefore, may be represented in Figure 84. Schmid and Wassermann report tests of tensile strengths in kg./mm.^{2} corresponding to zones for two specimens of hard drawn copper wire, as follows:

			Tensile Strength
(1)	Original diameter	4.85 mm.	38.3
	Etched to	3.20 mm.	41.3
	Drawn to	3.20 mm.	45.2
(2)	Original diameter	1.75 mm.	46.1
	Etched to	1.00 mm.	52.8
	Drawn to	1.00 mm.	51.0

[5] *Z. Physik*, **42**, 779 (1927).

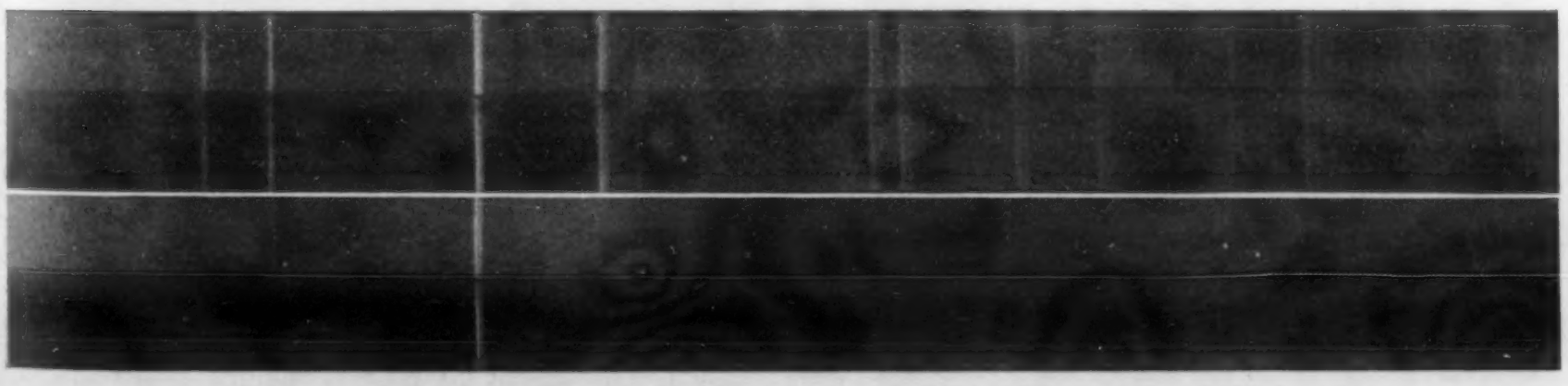


Figure 82—Hull Diffraction Patterns Showing Zonal Structure of Copper Wire: (Above) Outer Mantle; (Below) Core

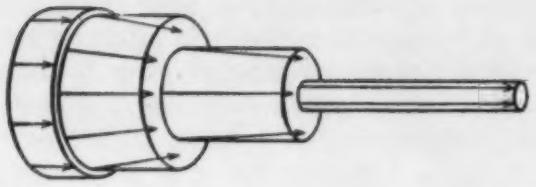


Figure 84—Diagram Showing Zonal Texture of Hard Drawn Wires

It is evident that the core zone of a wire has the highest tensile strength in keeping with its parallel preferred orientation. This anisotropic or zonal structure is an inherent property and improvement in the superficial zones is not gained by increasing the amount of cold work.

5. Summary of X-ray Results on Deformation Structures of Drawn Wires. All body-centered cubic metals when drawn are characterized by a [110] direction parallel to the direction of drawing; all face-centered cubic metals have a [111] direction in the wire axis, with a second orientation of [100], the proportion of crystal grains in the various metals varying as explained above. An exception in the case of copper wire recrystallized at 1000° C. has been noted in Section 8, Part IV. Only the core of these wires and perhaps the outermost skin approximate these orientations since in the mantle zones the fiber axis is inclined to the wire axis. In answering the question why a particular crystallographic direction becomes parallel to the direction of deformation it may be noted that the most thickly populated atomic planes in the body-centered cubic lattice are the (111) planes, with the (100) planes next most densely populated. It is a general drawing phenomenon, therefore, that the most densely populated planes take up positions perpendicular to the wire axis, and that these orientations are such as to present maximum resistance to further deformation.

6. Interpretation of Fiber Patterns for Rolled Sheets (Limited Fiber Structure). As explained above, crystal grains in a rolled sheet not only take up positions with a certain crystallographic direction parallel to the direction of rolling, but are further limited by having certain crystallographic planes parallel to the plane of rolling and to the transverse direction. The diffraction patterns enable the evaluation of the indices of these three characteristic directions (that is, rolling direction, the normal to the rolling plane, and the transverse direction lying in the rolling plane at right angles to the rolling direction), and also with remarkable accuracy the departure or scattering from the theoretically ideal orientation as is always observed in practical cases. The rolling direction may be readily ascertained by the methods outlined under drawing, although all of the diffraction interferences will not be present on account of the further limitation in rolling. For the determination of the crystallographic indices of the transverse direction and the normal to the plane of rolling, a further step must be taken. The best method is that of Glocker, explained in detail in his book:[6] a single metal crystal is considered to rotate through 360° around the known fiber axis, and the reflection angle θ of the X-ray beam, impinging at right angles to the axis of rotation, on the different lattice planes of the crystal is plotted as a function of the angle of rotation. The result is a series of rotation curves which are extremely useful in interpreting results on rolled sheets or foils. Glocker gives curves for fiber axes [112], [001] and [111], with octahedral (111), cubic (100), dodecahedral (110) and (113) planes for each. He considers in detail the case of rolled silver in which [112] is parallel to the rolling direction and (110) planes are parallel to the rolling plane.

7. Detailed Analysis of Pattern for Rolled Steel. To show in detail how a diffraction pattern of commercial rolled sheet may be completely interpreted, the example of low carbon sheet steel is selected. The following analysis of a pattern similar to Figure 85 was carried through by R. L. Davidson in three parts:

[6] "Materialprüfung mit Röntgenstrahlen," Berlin, 1927, pages 312–324.

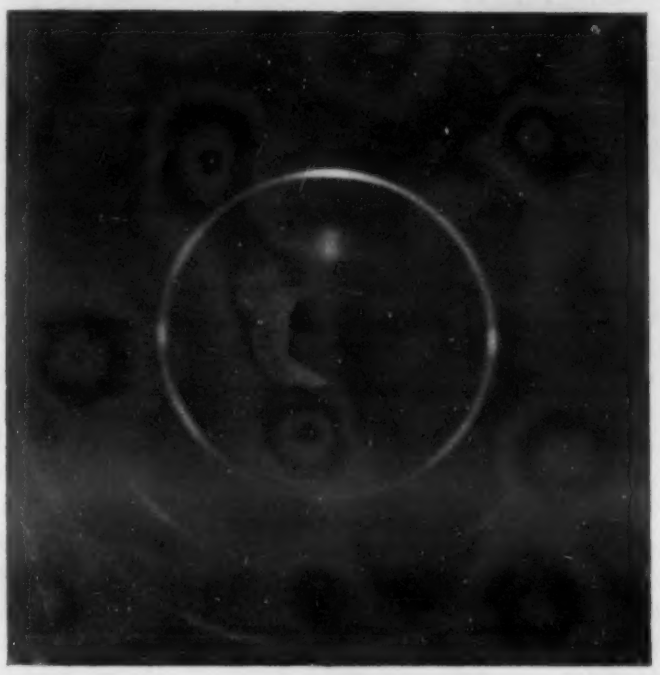


Figure 85—Fiber Pattern for Rolled Sheet Steel (for Complete Analysis See Text)

a. Identification of the diffraction rings.
b. Identification of the type of fiber orientation.
c. Determination of the type and degree of perfection of further limits of orientation.

The method consists essentially in assuming certain origins, orientations and limitations and in checking theoretically desired patterns against those experimentally obtained.

a. Identification of diffraction rings

If θ = angle of incidence of X-rays with atomic planes,
D = diameter of ring on film,
5 cm. = distance from specimen to film,
then $\theta = \frac{1}{2} \tan^{-1} (1/5 \times D/2)$.

D	$D/2$	Tan 2θ	2θ	θ	Sin θ (Observed)
3.76	1.88	0.376	20° 36′	10° 18′	0.179
5.66	2.84	0.566	29° 30′	14° 45′	0.255
7.28	3.64	0.728	36° 2′	18° 1′	0.309

Calculation of the theoretical values of sin θ assuming these plane families to be the (110), (200), (211)—

d = interplanar distances
a = length of unit cell cube of Fe = 2.87 A. U.
(hkl) = (100), (200), (211)

$$\lambda = 2 d \sin \theta, \sin \theta = \frac{\lambda}{2 d}$$

λ for Mo Kα = 0.710 A. U.

$$\text{Hence } \sin \theta = \frac{0.355}{d}$$

$$\text{and } d = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

hkl	d	Sin θ (Calculated)	Sin θ (Observed)
110	2.03	0.175	0.179
200	1.435	0.247	0.255
211	1.171	0.303	0.309

This is close enough agreement from these rough measurements to definitely establish the identity of these rings.

The inner broad band is caused by the polychromatic or white radiation reflected by the planes of greatest spacing (110). The inner edge is determined by the short wave length of the white radiation, which is determined by the peak voltage across the X-ray tube. The outer edge is caused by an absorption edge due to the silver of the film emulsion, which occurs at a wave length of 0.485 A. U.

To check this outer absorption edge, the following calculation is made:

$$\lambda = 0.485,\ \sin\theta = \frac{0.485}{2d} = \frac{0.485}{2 \times 2.03} = 0.120$$

Diameter of outer edge of ring = 2.50 cm.
$\sin\theta = \sin {}^1/_2 \tan^{-1}(1/5 \times D/2)$

D	$D/2$	Tan 2θ	2θ	θ	Sin θ (Observed)	Sin θ (Calcd.)
2.50	1.25	0.25	14° 2′	7° 1′	0.122	0.120

This agreement is also quite close.

The determination of minimum wave length from the diameter of the inside edge of the white radiation band is as follows:

Diameter of inner ring edge = 1.60 cm.

$$\frac{0.80}{5} = 0.16 = \tan 2\theta$$

$$\theta = 4.75°$$

$$\text{Sin } \theta = 0.083$$

$\lambda = 2d \sin\theta = 2 \times 2.03 \times 0.083 = 0.336$ A. U.
Peak voltage $= V = hc/\lambda e = 12354/\lambda = 36{,}768$ volts.

b. Identification of Fiber Orientation

Since the reflection of an X-ray beam from an atomic plane must always lie on a plane determined by the beam and a perpendicular to the atomic plane at the point of reflection, the azimuth of the spots appearing on the various rings can be determined by calculating the angle between the perpendicular of the atomic planes being considered and the fiber axis, which is placed perpendicular to the beam. Let us adopt the following notation—

α = angle between perpendicular to atomic planes under consideration and fiber axis.
δ = azimuth angle of spot on film (starting with zero at the 12 o'clock position on the film).
θ = angle of incidence of the X-ray beam upon atomic plane.

Polanyi gives the relation between these angles as $\cos\delta = \frac{\cos\alpha}{\cos\theta}$, but at such small values of θ as appear in these diagrams the cosine of θ so nearly equals one that it is within limits of accuracy to simplify to $\cos\delta = \cos\alpha$ or $\delta = \alpha$.

Thus the azimuth of an intensity maximum on any ring is directly the angle between the perpendicular to the plane family causing the ring and the fiber axis. This angle between a perpendicular to any family of planes (hkl), and any fiber axis (uvw) can be given by solid analytical geometery to be—

$$\cos\alpha = \frac{uh + vk + lw}{\sqrt{u^2 + v^2 + w^2}\ \sqrt{h^2 + k^2 + l^2}}.$$

Since Glocker gives the fiber axis direction in a sheet of iron as [110] this orientation will be assumed and the theoretically determined positions of the spots on each ring will be compared with the actual diagrams. With (uvw) as (110), the equation simplifies to

$$\cos\alpha = \frac{h + k}{\sqrt{2}\ \sqrt{h^2 + k^2 + l^2}}.$$

Using this equation the theoretical azimuth of spots on the various rings is as follows:

Planes	Azimuth
110	0°
$\bar{1}10$	90°
101	60°
100	45°
001	90°
112	55°
$1\bar{1}2$	90°
121	30°
$\bar{1}21$	73°

These diagrams should be symmetrical both along a vertical and a horizontal axis, for every spot at angle δ on the right there is one at δ on the left, and one on the right and left at $(180° - \delta)$.

In comparing this theoretical complete fiber diagram with the actual diffraction patterns let us bear in mind that we have assumed the fiber axis perpendicular to the X-ray beam which practically may not be exactly true. This will tend in some cases to shift the positions towards one pole or the other and cause fiber spots which originate from planes at high angles from the fiber axis to appear with less rotation than would be expected, as will be discussed in the next section.

In Figure 85 the following experimental interferences are observed:

Innermost sharp ring (110)—
0° missing
60° present
90° present

Second sharp ring (100)—
45° present
90° missing

Third sharp ring (211)—
30° present
55° missing
73° present
90° missing

The broad band can have the same intensity maxima as the sharp (110) ring—

0° present
60° missing
90° present

Since this orientation takes care of all the spots appearing on the diffraction pattern but calls for spots which do not appear, it is evident that the assumption of a [110] axis is correct, but that there is a further limitation of orientation in a rolled sheet.

c. Type and Degree of Perfection of Further Limitation

It has just been shown that as was expected, a cube face diagonal lies parallel to the surface of the sheet or nearly so and in the direction of rolling. The other condition of a cube face lying parallel to the surface of a sheet which is usually given, will be taken as the zero position and angular rotation about the face diagonal fiber axis necessary to cause the appearance of various spots will be calculated. Then, by the presence or absence of certain spots, the degree of perfection of the fulfillment of this condition can be determined on each film. If this orientation were perfect, only a very few spots would appear on any ring, and the ring itself would be missing.

The calculation of this angle of lateral rocking to one side and the other about the zero position necessary to cause the appearance of each spot is very involved in most cases, and a complete solution of this problem of a cubic lattice rotating about a [110] axis has been worked into the series of rotation curves by R. Glocker mentioned above. These curves were used in investigating how great an angle of rotation of the cube about the [110] fiber axis from the zero position of the (100) face in the sheet is necessary in order that a diffraction spot may occur by having fulfilled the law specifying the angle of diffraction.

It will be seen that in the special case of any planes containing the X-ray beam the necessary angle of rotation about any axis perpendicular to the beam will directly equal the angle θ given in the diffraction equation.

The presence of spots on the two (110) rings at the 12 and 6 o'clock positions can only be explained by another type of imperfection in orientation. This is a *tipping* of planes which in a perfect orientation would contain the X-ray beam and be perpendicular to the fiber axis, about an axis perpendicular to both the beam and the fiber axis. This is actually an *inclination of the fiber axis to the surface of the sheet*, and its calculation falls in the special case mentioned in the last paragraph. The angles of rotation necessary for the appearance of the various spots on the several rings arranged in the

order of their appearance with increasing rotation were found to be as follows:

Necessary Angle of Rotation	Ring	Radiation	Azimuth
4	110	White	90°
9	112	Kα	73°
10	110	Kα	90°
18	112	Kα	30°
18	110	Kα	60°
20	100	Kα	45°
22	110	White	60°
45	112	Kα	90°
70	112	Kα	55°

The angle of inclination of the fiber axis to the sheet necessary to cause the appearance of spots at the six and twelve o'clock positions on the rings will be calculated. These reflections can only originate from (110) planes, and the inclination is directly equal to the angle of incidence given by the Bragg equation for this set of planes.

Ring	Radiation	Wave Length	Inclination Angle
(110)	Mo Kα	0.710 A. U.	10° 18′
(110)	White	0.336	4° 45′

Inclination of the fiber axis to the surface of the sheet in both directions with respect to the direction of the last pass will have the effect of causing the spots to extend over a wider angle on the circles, and will cause spots to appear at slightly smaller rotation angles than those calculated to be necessary. If more grains are inclined in one direction than in the other, which in general seems to be the case, the intensity maxima will be displaced in one direction of azimuth and there arises a possibility of the appearance of spots on one side of the equator which have no corresponding spots on the other side.

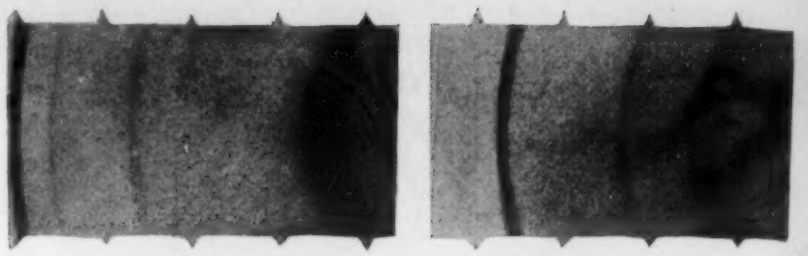
d. Experimental Check

For the particular specimen considered here the necessary rotation or the degree of imperfection of limitation of the complete fiber diagram caused by rotation around the fiber axis is 35°; the inclination of the fiber axis to the sheet estimated from the relative intensities of the two polar spots to each other and to other interference maxima is small; and the majority of the inclinations of the fiber axes are greater in one direction than in the other with respect to the direction of last pass through the rolls.

8. Summary of Experimental Results on Structures of Rolled Foils.

Metal	Lattice Type	Treatment	Fiber Axis [FA] Rolling Plane (RP)
Aluminum	F. C. C.	Rolled	I. [335] || FA, (135) || RP (4 positions possible)
			II. [100] || FA, (001) || RP (average reduction)
Silver	F. C. C.	Rolled	[112] || FA, (110) || RP (2 mirror image orientations)
		Recrystallized 250–800° C.	[112] || FA, (113) || RP
Gold	F. C. C.	Rolled	I. [112] || FA, (110) || RP
			II. [100] || FA, (001) || RP
Copper	F. C. C.	Rolled	[112] || FA, (110) || RP
		Recrystallized 250–1050° C.	[100] || FA, (001) || RP
α-Brass	F. C. C.	Rolled	[112] || FA, (110) || RP
		Recrystallized 300–702° C.	[112] || FA, (113) || RP
Platinum	F. C. C.	Rolled	I. [112] || FA, (110) || RP
			II. [100] || FA, (001) || RP
Iron	B. C. C.	Rolled	[110] || FA, (100) || RP
		Recrystallized 600°	[350] || FA, (100) || RP
Tantalum	B. C. C.	Rolled	Same as rolled iron
Tungsten	B. C. C.	Rolled	

9. Other X-Ray Evidences of Metal Fabrication. It is apparent that deformation producing preferred grain orientation and deformation producing lattice distortion and strain, as explained in Section 7, Part IV, may have no sharp line of demarkation and may appear simultaneously. Utilizing the Debye-Scherrer method and copper radiation, Dehlinger[7] has exhaustively studied the effects of cold work upon the diffraction lines. For cold-worked silver, copper, tantalum and α-brass, the copper-Kα doublet is not resolved, but for aluminum and zinc under the same conditions it is (Figure 86). The broadening of lines is not therefore due alone to the grain size or to the amount of working. The cause is attributed to periodic bending and distortion of the lattice, producing "lattice ghosts" which due to irregularity of bending may fuse with the principal diffraction lines. The whole matter may be treated, therefore, by theories of optics. The theory proves that a small strain extending throughout an entire crystal grain will lead to the observed broadening while large deformations localized in a portion exercise no measurable broadening. The plastic deformation of zinc is considered in Section 11.



a b

Figure 86—Comparison of Diffraction Line Breadths for Cold-Drawn (a) Tantalum and (b) Aluminum

10. The Structure of Electrodeposited Metals, Mirrors, Sputtered Films, etc.

1. Electrodeposited Metal Sheets. In the preceding section the production of a directed crystal orientation by means of mechanical work has been considered in detail. The question naturally arises as to whether crystals may actually *grow* in such a way as to have a common crystallographic direction parallel to an axis of growth. Experiment proves that electrodeposited metal films show a fiber structure similar to drawn metals, and that the grains grow out parallel to the stream lines of the current or perpendicular to the surface of the electrode. The interpretation of the fiber patterns leading to an evaluation of the indices of the fiber axes proceeds exactly as outlined in Section 9. Of course the fiber axis is parallel to the cross section or thinnest dimension of the deposited sheet. If, then, an X-ray beam was impinged at right angles upon the surface of such a sheet it would pass parallel to the fiber axis. As demonstrated for wires, the pattern is always indicative of random orientation since the crystal units may be oriented anywhere through 360° around the fiber axis. It is necessary, therefore, to have films thick enough to pass the beam perpendicular to the fiber axis or to use the method of inclining the fiber axis at an oblique angle to the primary beam. Bozorth[8] has published curves for graphical analysis of patterns so obtained with the formula

$$\cos \delta = \frac{\cos \alpha - \cos \beta \sin \theta}{\sin \beta \cos \theta}.$$

Many excellent papers have been published on detailed studies involving effects of electrolytes, current density, temperature, concentration, stirring, orientation as a function of thickness, effect of base electrode metal, recrystallization, presence of

[7] *Z. Krist.*, **65**, 615 (1927).
[8] *Phys. Rev.*, **26**, 310 (1925).

small amounts of addition agents, pH, electrode potential, etc. Glocker summarizes the results as follows:

Element	Lattice	Solution	Current Density Amp./Cm.[2]	Fiber Axis	Observer
Silver	F. C. C.	Cyanide	0.007	Random	Glocker and Kaupp
Silver	F. C. C.	0.1 *N* $AgNO_3$	0.010	[111], [001]	Glocker and Kaupp
Silver	F. C. C.	0.1 *N* $AgNO_3$	0.022	Random	Glocker and Kaupp
Copper	F. C. C.	0.1 *N* $CuSO_4$	0.03	[011]	Glocker and Kaupp
Nickel	F. C. C.	$Ni(NH_4)_4SO_4$ or 0.1 *N* $NiCl_2$ + 0.9 *N* $NiSO_4$	0.005	[001]	Bozorth[9]
Nickel	F. C. C.	$NiSO_4$ + boric acid	0.10	[001] [011] (on underlying copper)	Clark and Frolich[10]
Nickel	F. C. C.	0.9 *N* $NiCl_2$ + 0.1 *N* $NiSO_4$	0.005	[211]	Bozorth
Lead	F. C. C.	$Pb(ClO_4)_2$ or fluosilicate	1.0	[211]	Clark, Frolich and Aborn[11]
Chromium	B. C. C.	Grube		[111]	Glocker and Kaupp
Iron	B. C. C.	10% $Fe(NH_4)_4SO_4$	0.001	[111]	Glocker and Kaupp
Iron	B. C. C.	10% $Fe(NH_4)_4SO_4$	0.015	Random	Glocker and Kaupp
Iron	B. C. C.	50% $FeCl_2$	0.001	[111]	Glocker and Kaupp
Iron	B. C. C.	50% $FeCl_2$ at 100° C.	0.1	Random	Glocker and Kaupp
Iron	B. C. C.	Same + $CaCl_2$	0.1	[112]	Glocker and Kaupp

Figure 87 shows the pattern for a lead dendrite, an electrolytically formed film of lead deposited from fluoborate electrolyte showing large random grains, and a film deposited under the same conditions except for the addition of 0.5% gelatin to the electrolyte.

2. **Deposition of a Metal from Solution by Displacement.** Metallic silver deposited from a solution of silver nitrate by introducing a small piece of copper has a fibrous structure with the axis [110] which makes an angle of 30° with the direction of growth. The micro-crystals show a rotation around this axis with an angle of ±11°. As the (111) planes of the silver crystals lie parallel to the flat surfaces of the deposited metal, the direction of growth of the deposited silver lies nearly parallel to the [112] axis.[12]

3. **Constitution of Films from Mixed Electrolytes.** Nakamura[13] has found that the lattice constant of a film deposited from a mixed copper and zinc electrolyte analyzes 82.48% copper and has a face-centered cubic lattice with the parameter 3.62 A. U. This is exactly the same as for cast α-brass of the same constitution. This proves that the solid solution of copper and zinc is formed even by the electrolytic process. The general phenomenon of solid solution or chemical combinations instead of mixtures has been confirmed by Roux and Cournot.[14]

4. **Properties of Mirrors and Sputtered Films.** Very thin films of metals have been frequently studied. Foils of platinum, nickel and copper 7 to 18μ thick produced by cathodic sputtering and thermal evaporation show a structure. The support upon which the film is deposited has a profound effect upon the crystal arrangement.

An interesting study has been made of sputtered nickel films by Ingersoll and Hanowalt.[15] With the use of a special deposition tube which allowed the withdrawal of the cathode without altering vacuum conditions, films of nickel have been sputtered in residual atmospheres of hydrogen, helium, nitrogen and argon, and their gas content investigated. This is large, though in general not reaching one molecule per atom of metal. Upon heating, the gas is emitted copiously at 300–400° C., which is just the baking temperature range for which such films become magnetic and also much better conducting. As permeability is supposed to be a rapid inverse function of atomic distance it seems probable that the gas, by keeping the atoms apart, is primarily responsible for the abnormal magnetic and other properties of such films, although it is impossible to separate this effect entirely from the factor of crystal structure. Resistance measurements made during baking on a series of sputtered and evaporated films indicate that the evaporated film contains much less gas than the sputtered even when produced in the same gas pressure. This may be explained on the basis of the excitation or activation of the gas during the sputtering process, which promotes its occlusion—sometimes as a compound with the metal. When care is taken to avoid undue heating during sputtering the film may be amorphous, or, when produced in hydrogen or nitrogen may be crystalline with a lattice somewhat different from the normal, pointing to the existence of nickel hydrides and nitrides produced in the activated gas in sputtering. Definite evidence of helium or argon compounds is lacking. These films also possess to a remarkable extent the ability to absorb or "clean up" hydrogen when a certain critical temperature is exceeded. This temperature depends on the previous heat treatment given the film and may be as low as 100° C. The amount of hydrogen absorbed is many times that required for

[9] *Z. Physik*, **24**, 121 (1924).
[10] *Z. Elektrochem.*, **31**, 649, 655 (1925).
[11] *Trans. Am Electrochem. Soc.*, April, 1926.
[12] *Tsuboi, Kyoto Coll. Sci. Memoirs*, **11**, 271 (1928).
[13] *Sci. Papers Inst. Phys. Chem. Rev.*, **2**, 287 (1925)
[14] *Compt. rend.*, **186**, 1733 (1928).
[15] *Physical Rev.*, **34**, 972 (1929).

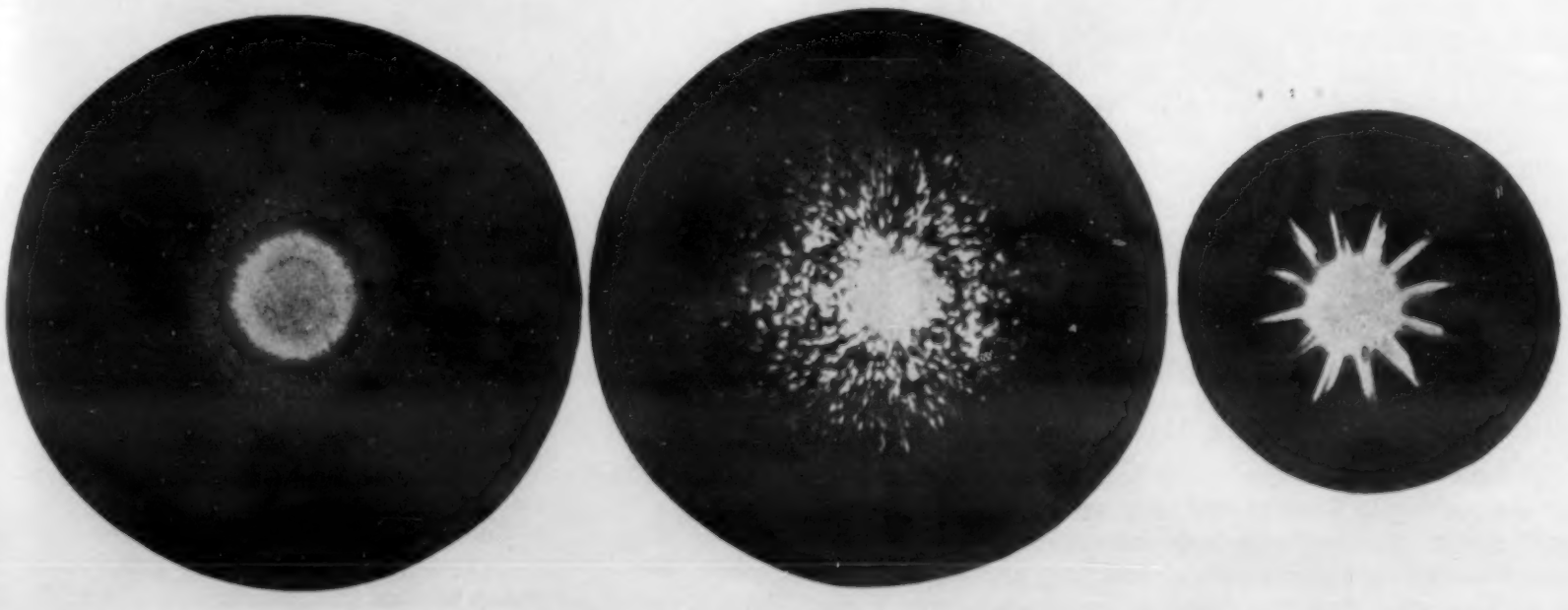


Figure 87—Structures of Electrodeposited Lead
Center—deposit from fluoborate electrolyte Left—same with 1/2% gelatin Right—lead dendrite

a unimolecular layer for the superficial area of the film. The hydrogen shows no effect on the crystal lattice and as the higher the baking temperature (i. e., the larger the crystals) the less the absorption, the gas is supposed not to enter the crystal structure but to be located in the inter-crystal region. This may be typical of gas absorption in general—excepting such cases as palladium-hydrogen.

5. Passive Metals. An interesting application has been the attempt to investigate passive metals upon the assumption that a very thin layer of oxide is the cause. Krüger and Nähring,[16] for example, give results of the X-ray examination of finely powdered passive iron, nickel and chromium by the Debye-Scherrer and Bohlin-Seeman methods. In no case does the photograph show lines corresponding with a known or unknown oxide of the metal, although these should be apparent if an oxide layer 10^{-7} cm. in thickness were present. These results are not in agreement with the view that solid layers of oxide are present on these metals in the passive state. The existence of a molecular layer of oxygen, which Tammann suggests may cause passivity—the free valencies of the metal at its surface being saturated by oxygen atoms, while the metal-lattice remains unchanged—would not be detectable by X-ray examination.

11. Practical Applications of X-Rays to Problems of Metallurgical Industry

In the preceding sections of this paper the fundamentals of X-ray metallography have been outlined. It is now the purpose to enumerate very briefly some of the actual problems of practical metallurgy, except the constitution and structure of alloys presented in full in Part III, which have been attacked by X-ray research and to illustrate some of the results. This list is merely representative and is in no sense a complete record of achievement. Most of the examples have been selected from among the investigations in the writer's own laboratory, several of them previously unpublished.

In general, the X-ray method has been called upon to decide upon the proper method of manufacturing technic, to assure constant properties and to make a fundamental distinction between metal or alloy commodities with satisfactory and unsatisfactory behavior. For commercial metals the scientific methods of interpretation derived for pure materials as presented in this paper are applied, although every new metal specimen is a new subject for research in itself. Gradually metallurgical industry is coming to the realization on the one hand that there is nothing mysterious in X-rays or magic in the searchings of ultimate structures, and on the other hand that these rays are not a panacea for all troubles unsolvable by other methods even though a brilliant record of achievement is already written. X-rays enable the observation of the interior of solid objects for gross inhomogeneities, and they extend the scope of fine structure analysis far beyond the microscope down to the ultimate architectural pattern of atoms in space. Without undue enthusiasm it may be stated as a fact that the contributions of X-ray research to metallurgical science *over so few years* surpass the record of all other experimental methods. The growing interest and confidence in a great research tool are demonstrated by the number of experimental installations in the research laboratories of metallurgical manufacturers and universities. A recent report of Subcommittee 6 of Committee E4 of the American Society for Testing Materials lists these present installations.

1. Annealing of Cast Steel. Figure 88 shows the structures of cast steel as cast with large internal strain, of this steel annealed according to commercial practice, and of the same steel with an ideal structure obtained by the selection of correct temperature and time of heat treatment through the agency of X-ray diffraction patterns. One of the great manufacturers of castings was annealing large steel pieces for 6 hours at a somewhat indefinite temperature. A short X-ray investigation proved beyond question that the correct temperature of annealing could be determined within $\pm 10°$, and that under these conditions a greatly improved structure was obtained not in 6 hours but in $^1/_2$ hour. The economic value of such a single discovery is at once evident in speeding production twelve-fold without additional expense. Such examples in this general field of heat treatment for the removal of strains and directional properties might be multiplied many times.

2. Magnetic Properties as a Function of the Structure of Silicon Electric Steels. Figure 89 reproduces again the first series of pinhole diffraction patterns ever made for silicon steel strips with varying magnetic hysteresis loss as noted. If the grain boundaries have not been unduly thickened by overheating in the annealing furnace, the magnetic loss may

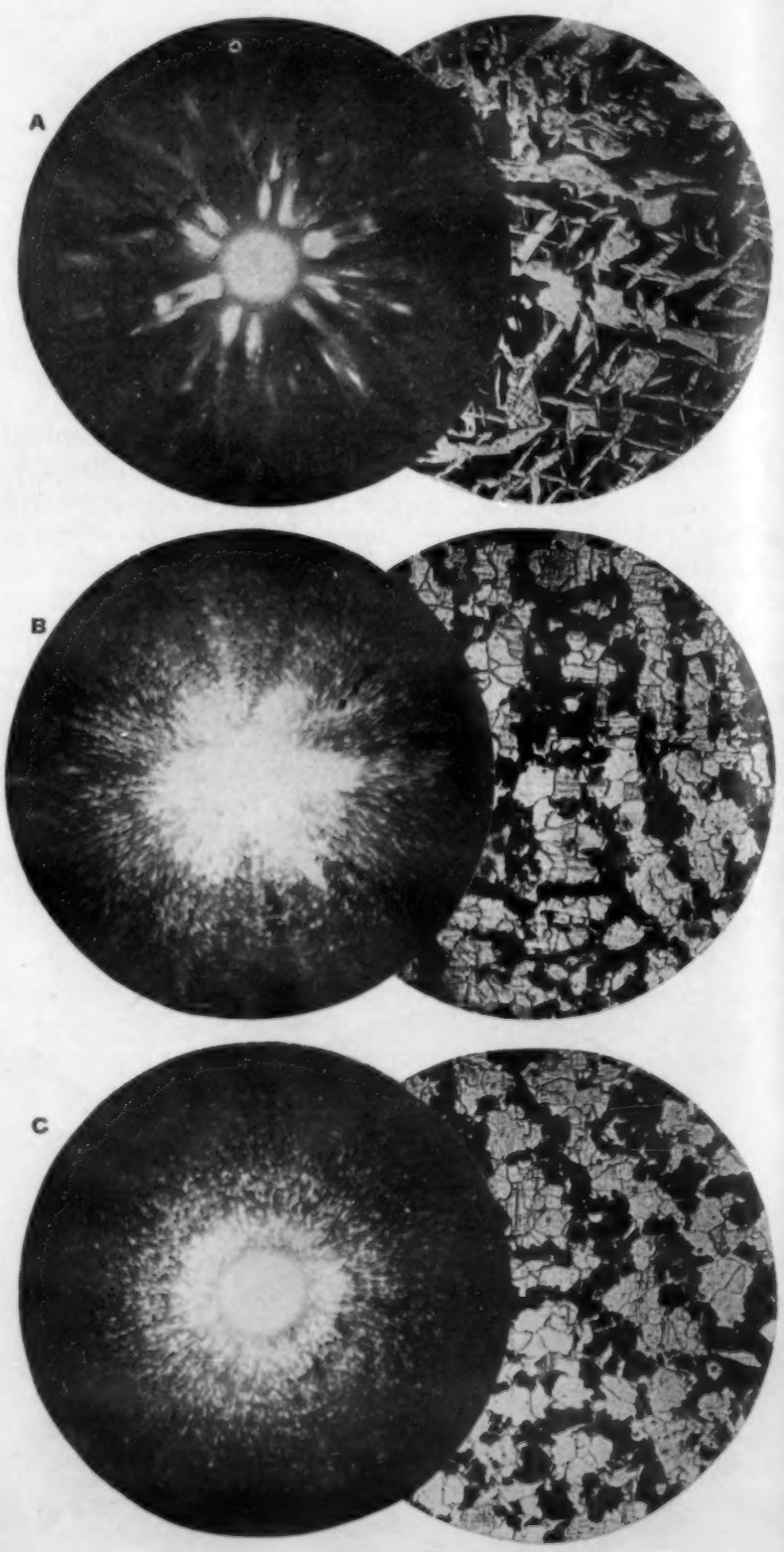


Figure 88—Cast Steel Structures

a—as cast
b—commercial anneal
c—ideal anneal

[16] *Ann. Physik*, **84**, 939 (1927).

be calculated empirically from the number and size of diffraction spots on a given area of the various patterns. Occasionally some strips may be unusually brittle and have unaccountably high loss. In every case an X-ray examination proves that the large single grains have an extraordinary orientation of crystallographic planes with respect to the surface of the sheet due to an uncontrolled factor in the rolling or annealing operation. In the ordinary case it will be remembered that iron grains in a rolled sheet are oriented with a [110] direction parallel to the direction of rolling and (100) planes in the surface of the sheet. The Epstein test for measuring magnetic loss usually employs 100 or more strips and an average value is of, course, measured. On several occasions in the writer's laboratory it has been possible by single patterns to separate a bundle into at least 5 groups, 2 with a lower loss, 2 with a higher and one with the same average loss of the whole original bundle. Further studies will undoubtedly lead to the production and selection of steel for cores with such lowered magnetic losses that the size of electrical machinery for a given load may be markedly reduced.

3. **Structure of Welds.** Figure 90 shows the comparison of a weld of the same steel made by the ordinary arc method and by the hydrogen atmosphere method. The former is characterized by very small, highly distorted grains (radial striations), and the latter by much larger, random unstrained grains with requisite strength and ductility.

4. **Forming Steels.** One of the great contributions has been to define specifications in terms of structure for forming steels, especially since unstrained and random properties are essential. Figure 91 shows patterns and photomicrographs for supposedly four grades of forming steel, soft, quarter hard, half hard and hard. In reality, as the patterns and also the Erichsen tests demonstrate, there are only two grades essentially. Satisfactory and unsatisfactory forming steels are easily differentiated by the patterns in Figure 92. The latter retains a residual preferred orientation of grains introduced in the original rolling; hence the annealing has been entirely inadequate and failure in the forming operation can be predicted definitely from such a pattern. Figure 93 demonstrates the structure of a sheet after successful forming and Figure 94 contrasts and explains why another sheet failed.

Figure 90—Comparison of Structures of Steel Welds: Left, Ordinary Arc Method; Right, Hydrogen Atmosphere Method

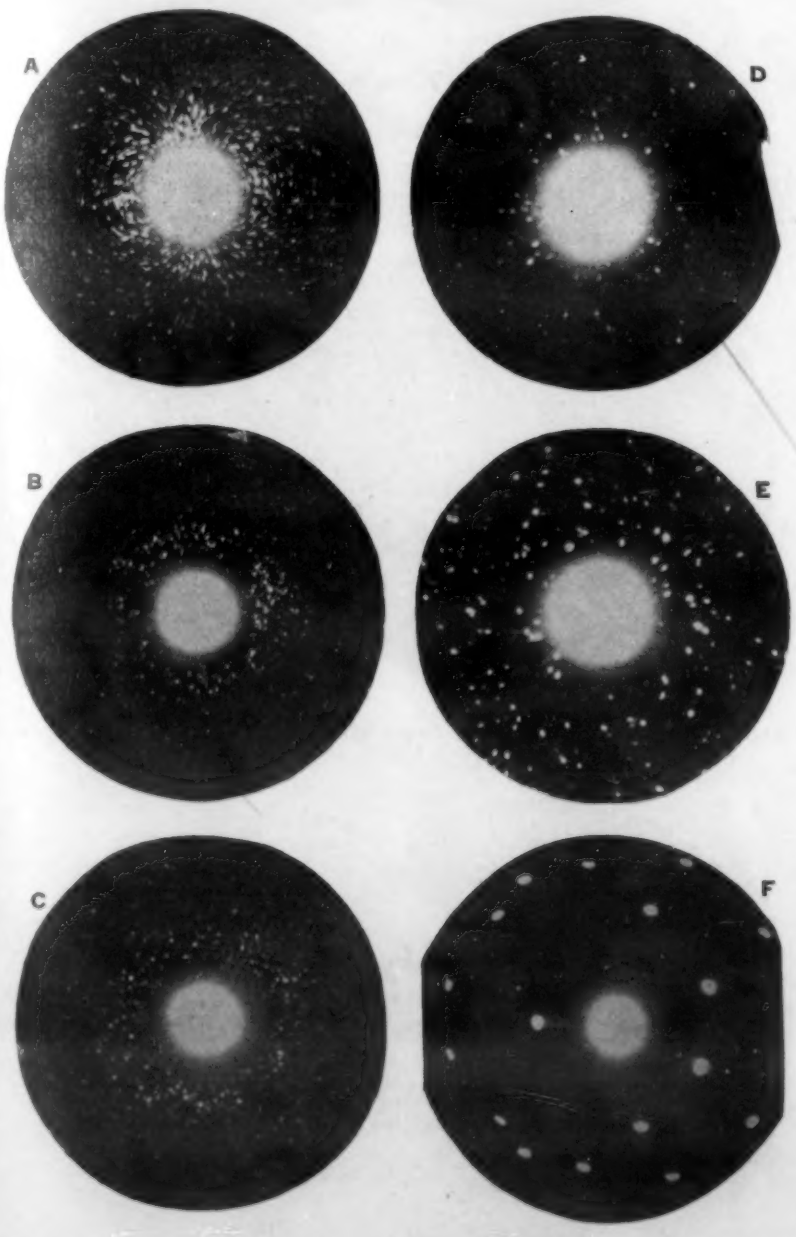


Figure 89—Structures of Silicon Electric Steel after Various Anneals, Showing Progression in Pattern with Decreasing Magnetic Hysteresis Losses in Watts Per Lb. as Follows: a (Poorest) 0.8636; b, 0.8181; c, 0.8068; d, 0.7727; e, 0.6931; f (Best) 0.5535.

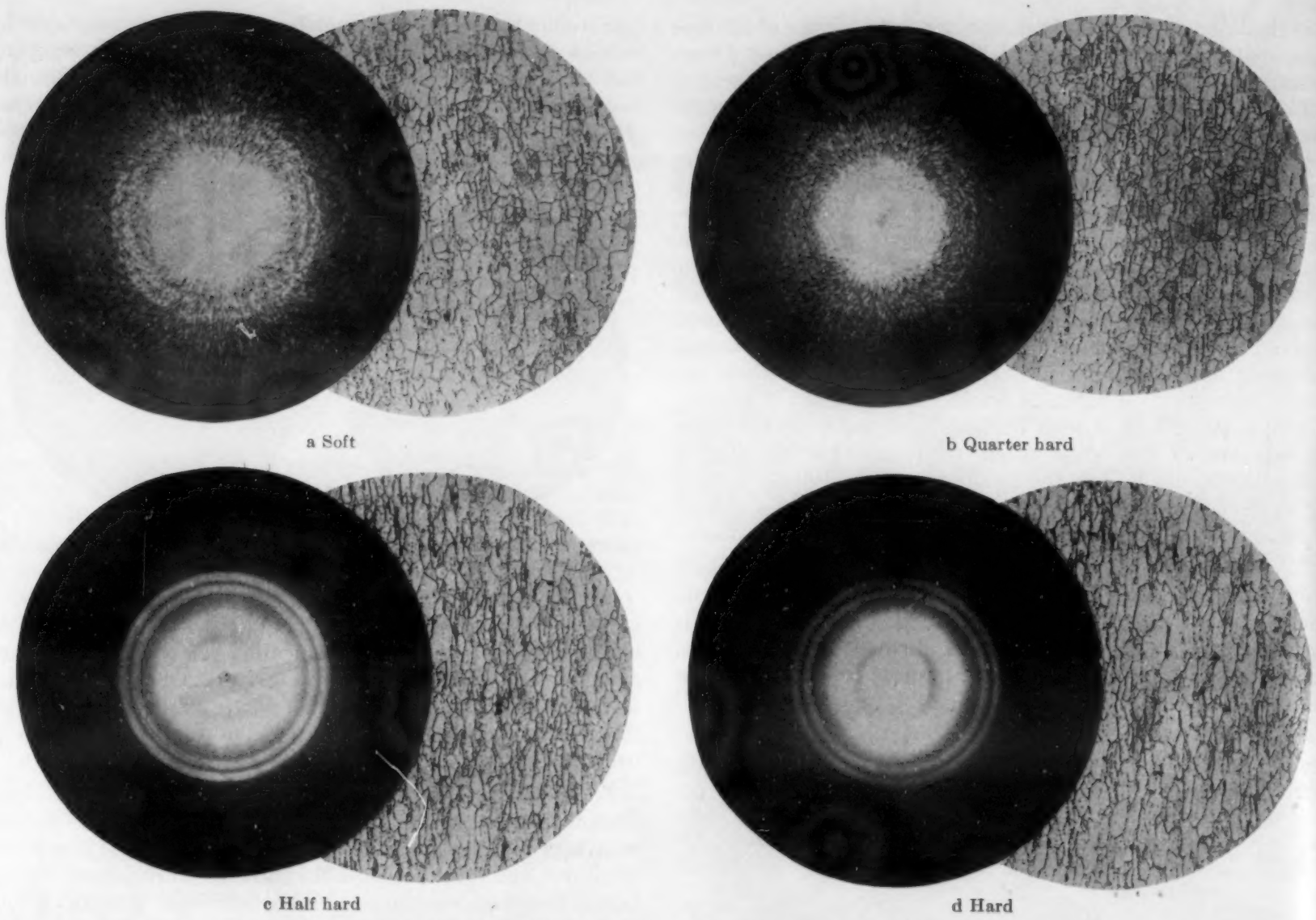
5. **Forming Copper.** Phillips and Edmunds[17] have demonstrated that hard-rolled copper has a pronounced fiber structure with [353] as the fiber axis, instead of [112] as found by others, and (110) planes in the surface. A preferred orientation is found in the annealed sheet which forms ears on cupping, while that which forms without ears has random orientation. The formation of ears in drawn copper is avoided by the limitation of rolling reduction to 65% and annealing at 500–600° C.

6. **Neumann Bands in Ferrite.** Mathewson and Edmunds[18] in a remarkable X-ray study by the Laue method have definitely settled the long controversy over the origin of these bands by proof of twinning along planes of the form [211].

7. **Plastic Deformation of Zinc.** Unusual interest has been attached to the X-ray study of the deformation of zinc both as single crystals and as polycrystalline aggregates. The following résumé of earlier investigations is quoted from "The Science of Metals" by Jeffries and Archer.

"Mark, Polanyi and Schmid in Germany studied the deformation of single crystals by means of X-ray crystal analysis. They found change of orientation at slip planes produced during the ordinary tensile test in single crystals of zinc. Conditions for maximum elongation of single crystals of zinc were determined. Zinc crystallizes with a hexagonal space lattice. The plane of easiest slip is the base of the unit hexagonal prism. When this plane makes an angle of approximately 45 deg. with the wire axis, the crystals are very ductile. Single crystal wires broken in tension at room temperature have shown as much as 600 percent elongation; broken at 205° C., elongations up to 1700 percent have been obtained. Although zinc is not regarded as very ductile, these values for elongation are the highest of any known metal. Unless the plane of easiest slip is at an opportune angle with respect to the wire axis, the crystal is relatively brittle. Single crystal wires of bismuth were tested at 200° C. and showed up to 300 percent elongation. In this case also the plane of easiest slip must make an angle with the wire axis of about 45 deg. or the crystal will be brittle when broken in tension. During the process of elongation of the zinc single crystals, the round wire changed into a flat ribbon.

[17] *Proc. A. S. T. M. Preprint*, **48** (1929).
[18] *Am. Inst. Min. & Met. Eng., Tech. Pub.* **139** (1929).



a Soft

b Quarter hard

c Half hard

d Hard

Figure 91—Commercial Grades of Forming Steels: a, Soft; b, Quarter Hard; c, Half Hard; d, Hard

	A	B	C	D
Thickness	.031″	.031″	.031″	.031″
Ericksen (Depth of cup)	0.430″	0.421″	0.276″	0.238″

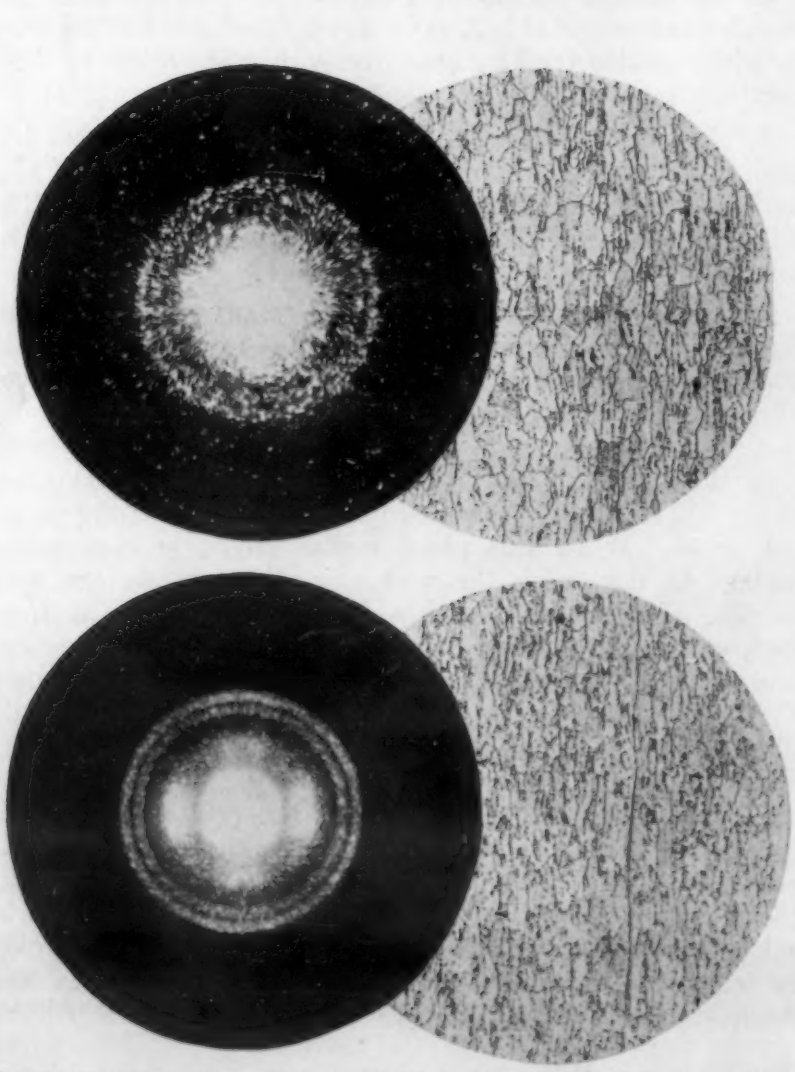


Figure 92—Diffraction Patterns and Photomicrographs of Forming Steels; Top, Formed Satisfactorily; Bottom, Failed in Forming Operation

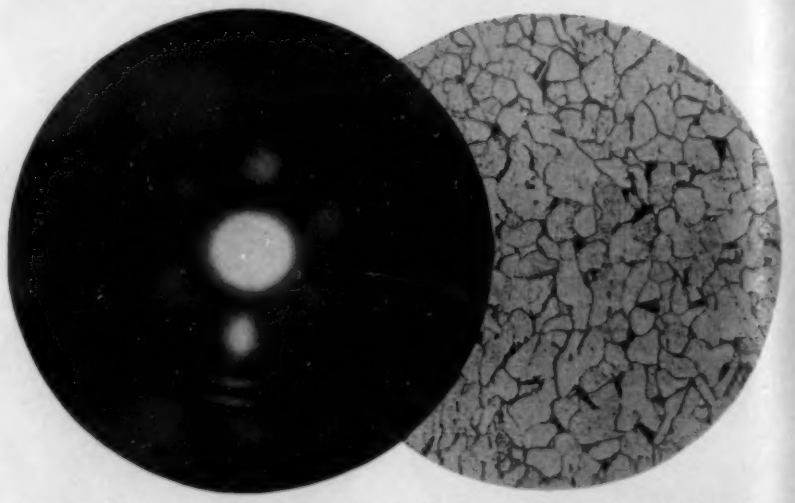


Figure 93—Structure of Forming Steel after Satisfactory Forming (Compare with Figure 94)

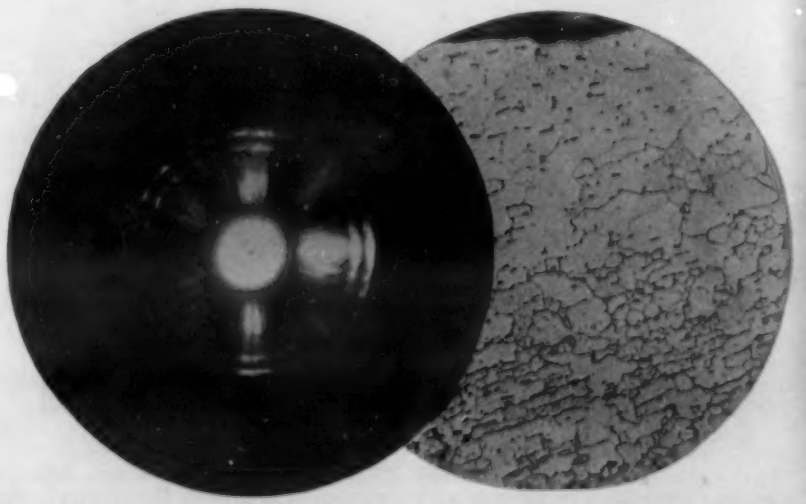


Figure 94—Structure of Forming Steel after Unsatisfactory Forming; Note Non-Uniform Pattern and Structure

The width of the ribbon was at first slightly wider than the original diameter of the wire. Slip occurred in a plane about 45 deg. from the wire axis and extended across the whole cross-section of the wire in such a manner that the intersection of each slip plane with the wire surface formed an ellipse. The slight widening of the ribbon was due to the rotation of the elliptical sections. As the elongation increased, the general orientation of the crystal changed, so that the angles of the easiest planes of slip became more nearly parallel with the direction of extension.

"The elongation is accompanied by a continued strengthening of the crystal and Polanyi believes that this is due to a bending of slip planes, so that the resistance to slip is increased. The exact mechanism of this strengthening is rather uncertain, but Polanyi assumes that the crystal units themselves undergo inner changes which lead to this result. As a matter of fact, Geiss and von Liempt have concluded from their investigations on single crystals of tungsten that the atoms themselves are deformed by tension, but the only evidence adduced by them for this conclusion is the change in temperature coefficient of resistance."[19]

Mathewson and Phillips[20] have described a new mechanism of deformation of zinc based on the study of large rectangular crystals. One of their conclusions was that deformation produced twinning with a rotation of some of the basal planes into positions 94° removed from their original position, or about the same as that of the prismatic planes before twinning. A second conclusion was that fracture occurred along the basal planes in their new position, and therefore that fractures previously regarded as prismatic were in reality basal. Wilson and Hoyt[21] showed then that cold rolling of polycrystalline zinc strip causes rearrangement of the zinc crystals not by twinning but in accordance with the classical theory of plastic deformation. Extension of slender zinc single-crystal specimens causes rearrangement of the basal planes in accordance with the classical theory, the single crystal structure being preserved. The formation of the after-elongation thread is accompanied by severe lattice deformation which

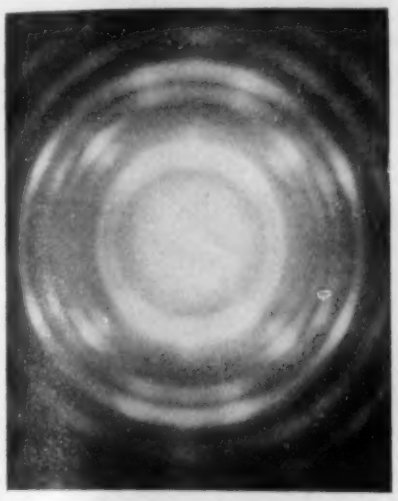


Figure 95—Diffraction Pattern for Cold-Rolled Molybdenum Resistor Ribbon (U. S. A.)

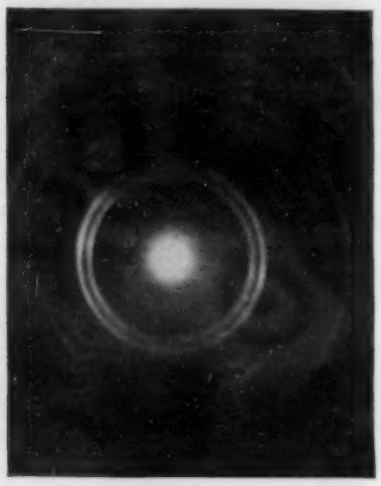


Figure 96—Cold-Rolled Molybdenum Resistor Ribbon (German Process)

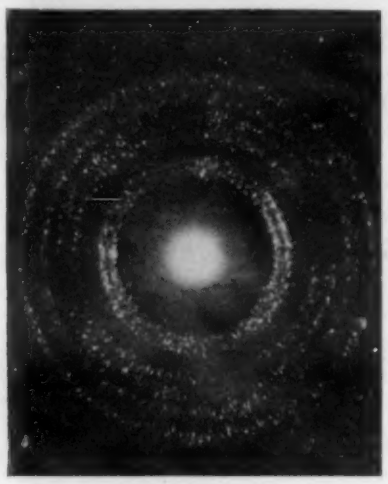
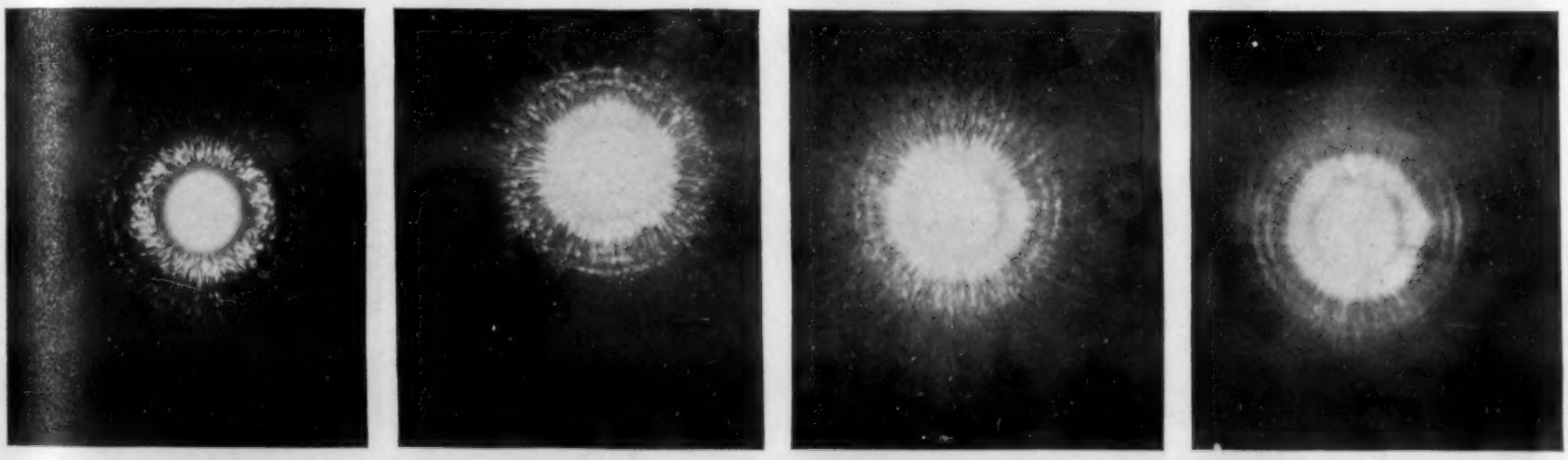


Figure 97—Pattern for Molybdenum Ribbon after Use in Electric Furnace, Showing Marked Grain Growth

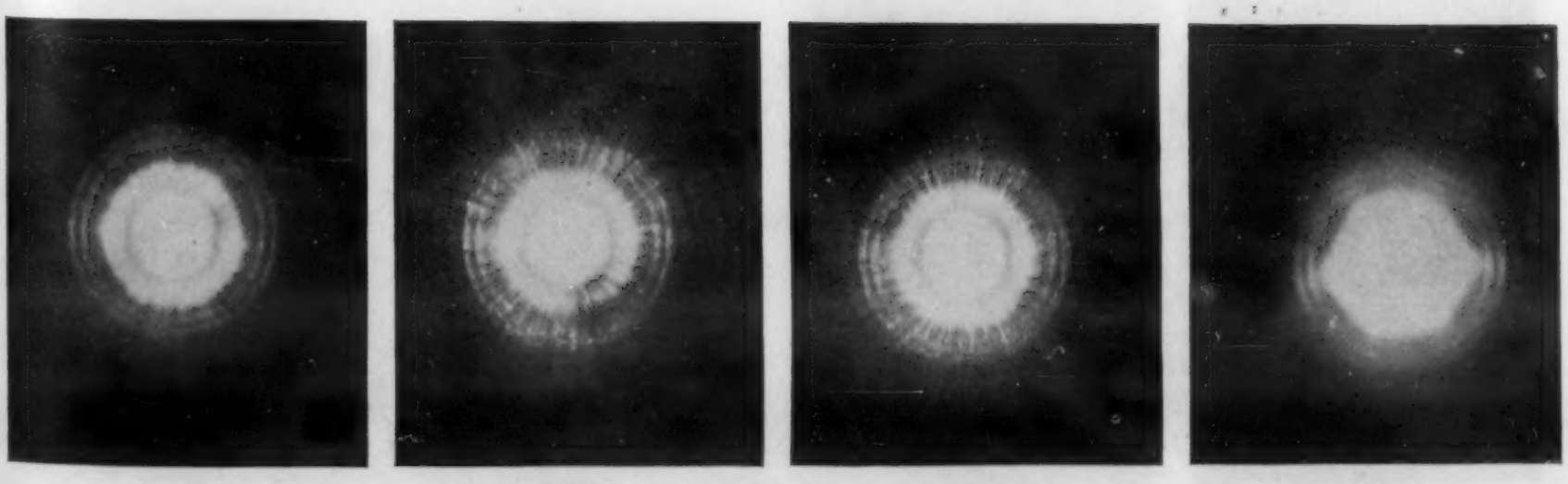
[19] Dushman, Edgar Marburg Lecture, *A. S. T. M.*, 1929.

[20] *Proc. Inst. Metals Div. A. I. M. E.*, **1927**, 143.

[21] *Am. Inst. Min. & Met. & Eng., Tech. Pub.* **25** (1927).



Original 1 twist 3 twists 5 twists



7 twists 9 twists 13 twists 38 twists

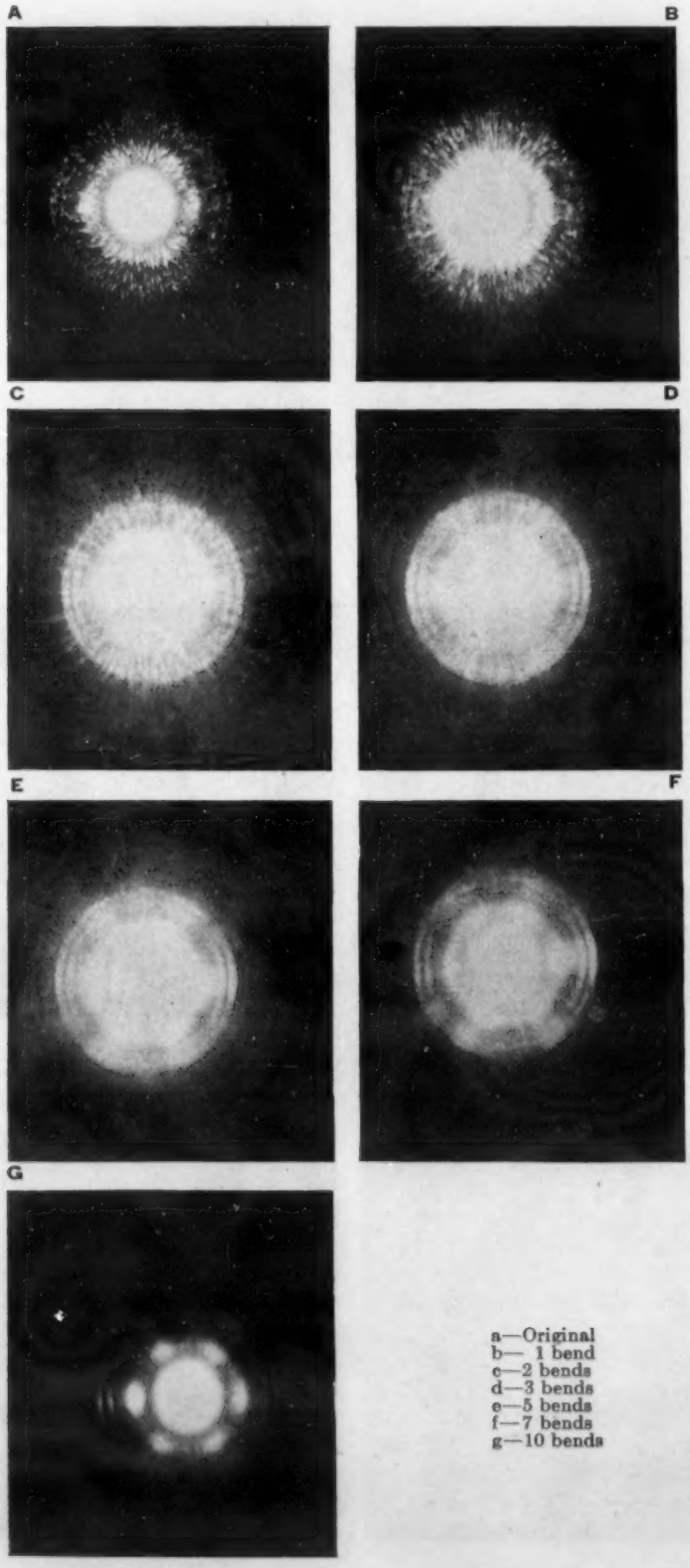
Figure 98—Patterns for Steel Wire after Twisting, Showing Fragmentation and Fibering

promotes twinning and fragmentation, though the single crystal structure seems very permanent. The fracture of a thick zinc crystal occurs as depicted above with twinning present. The fracture of slender zinc crystals under simple tension is prismatic with twinning absent.

8. Changes in Electric Furnace Resistor Ribbon.[22] Figures 95 and 96 show the patterns of 2 types of cold-rolled molybdenum ribbon used in resistance furnaces, while Figure 97 demonstrates what happens after short usage—a very large growth of grains.

9. Crystal Structure of White-Fractured and Reclaimed Malleable Iron.[22] It is well known that malleable iron suffers embrittlement when quenched from the blue heat zone, but that this is prevented by quenching from just under the A_1 point. This might be explained as due to changes in structure of the ferrite grains or to grain boundaries. The X-ray diffraction pattern of normal black-fractured malleable shows spotted rings indicating random orientation of fairly large grains, and considerable strain as shown by the radial asterism streaks. Malleable iron embrittled by quenching from 460°, that quenched from 650–700°, that embrittled by quenching from 450° and reclaimed by quenching from 700°, the same plus an additional quench from 450° which produced no embrittlement, all gave nearly identical diffraction patterns. The explanation of observed properties is evidently related to the grain boundaries which under the experimental conditions were not registered.

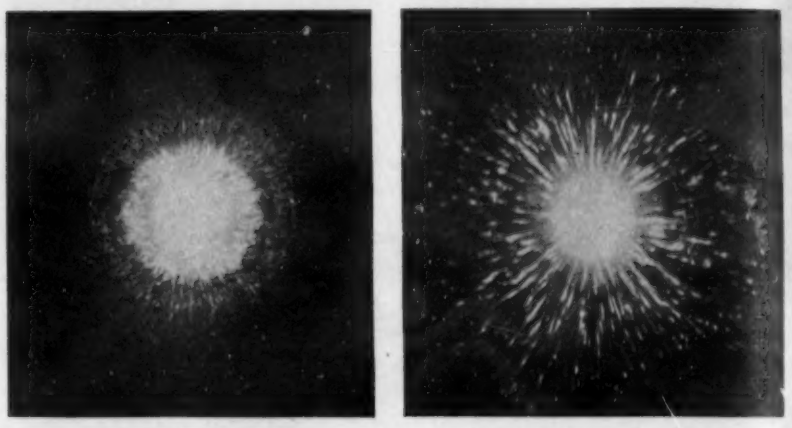
[22] Patterns furnished by N. P. Goss



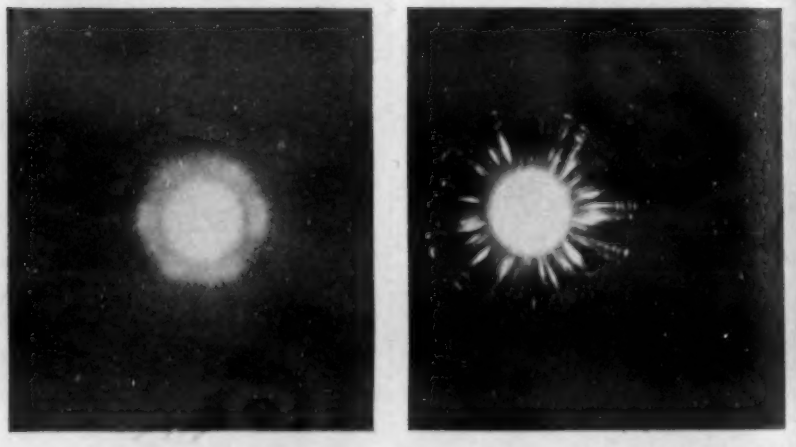
a—Original
b— 1 bend
c—2 bends
d—3 bends
e—5 bends
f—7 bends
g—10 bends

Figure 99—Patterns for Steel Wire after Bending Tests

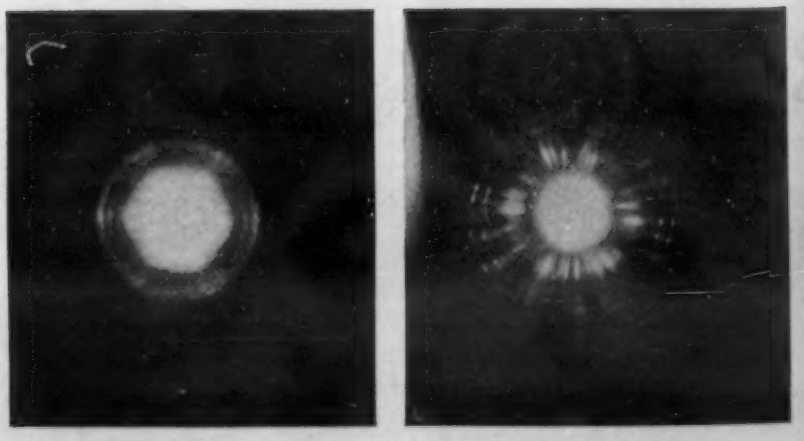
10. Comparison of Effects of Twisting and Bending Steel Wires. (0.60% C. Annealed at 1200° F.).—The original structure of the wire is shown in Figure 98 together with the patterns, respectively, after 1, 3, 5, 7, 9, 13 and 38 twists. Grain fragmentation begins with the first twist and reaches a maximum between 3 and 5 twists, followed by a



Original (small grains) Original (large grains)



After 5% reduction After 5% reduction



After 15% reduction After 15% reduction

Figure 100—Comparison of Effects of Drawing Reduction on Small and Large Grain Steel, Showing Fibering for Former

much more gradual effect. After 13 twists the beginning of fibering or preferred orientation is evident, and this is quite marked for the case of 38 twists.

For the bending tests the wire was bent through an angle of 90° and returned to its original position. The next bend was made in the opposite direction, the third like the first, etc. Figure 99 shows the effects of 1, 2, 3, 5, 7 and 10 bends. Severe grain fragmentation begins with 1 bend since the pattern is more diffuse. Two bends were equivalent to 13 twists in this respect; 3 bends introduces preferred orientation which becomes more perfect up to the breaking point. The bending test, therefore, is much more severe.

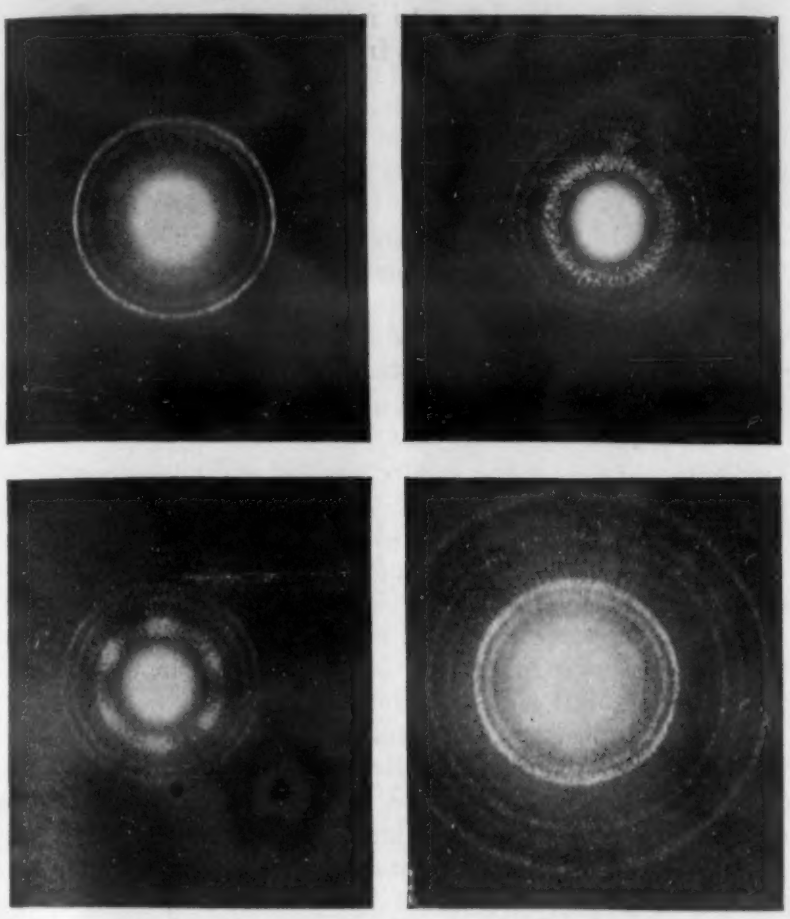


Figure 101—Patterns from Specimens in Same Lot of 0.10% C Bessemer Continuous Mill Rod, Showing Non-Uniformity of Structure

11. The Effect of Constitution on the Structure of Wires Drafted and Annealed (Basic Open Hearth and Acid Bessemer Steel).[22] Two series of steel wires of the same analysis essentially (carbon 0.10%) except for phosphorus (0.018 (A) and 0.102 (B)) were studied. Among many interesting differences in behavior are the following: under identical conditions after drafting 10% and annealing at 1300° for 1 hour, recrystallization has begun in A, but not at all in B; with 15% drafting and annealing at 1100° F. for 1 hour, recrystallization in A is nearly complete with very large grains but not perfectly random, while in B a very much smaller grain size and larger residual fibering is shown. Both produce random recrystallization for 15% drafting and annealing at 1200° F. for 1 hour, but the grain size of A is still appreciably greater than that of B. After annealing temperatures of 1600° F. complete recrystallization occurs in both with random distribution and freedom from distortion. The impurities in Bessemer wire clearly tend to retard grain growth and to retain directional properties introduced in cold working.

12. Twinning in Annealed Cold Rolled Steel. (C = 0.06%, Mn 0.35%, 0.002 inch thick).—The effects of annealing this material have been shown in Figures 67 to 72, Part IV. It is evident that below 1200° F. large grains grow in random orientation, but above 1200° to the upper critical temperature an orientation different from that in cold rolling (rolling direction [110], (100) planes in place of rolling) is developed.

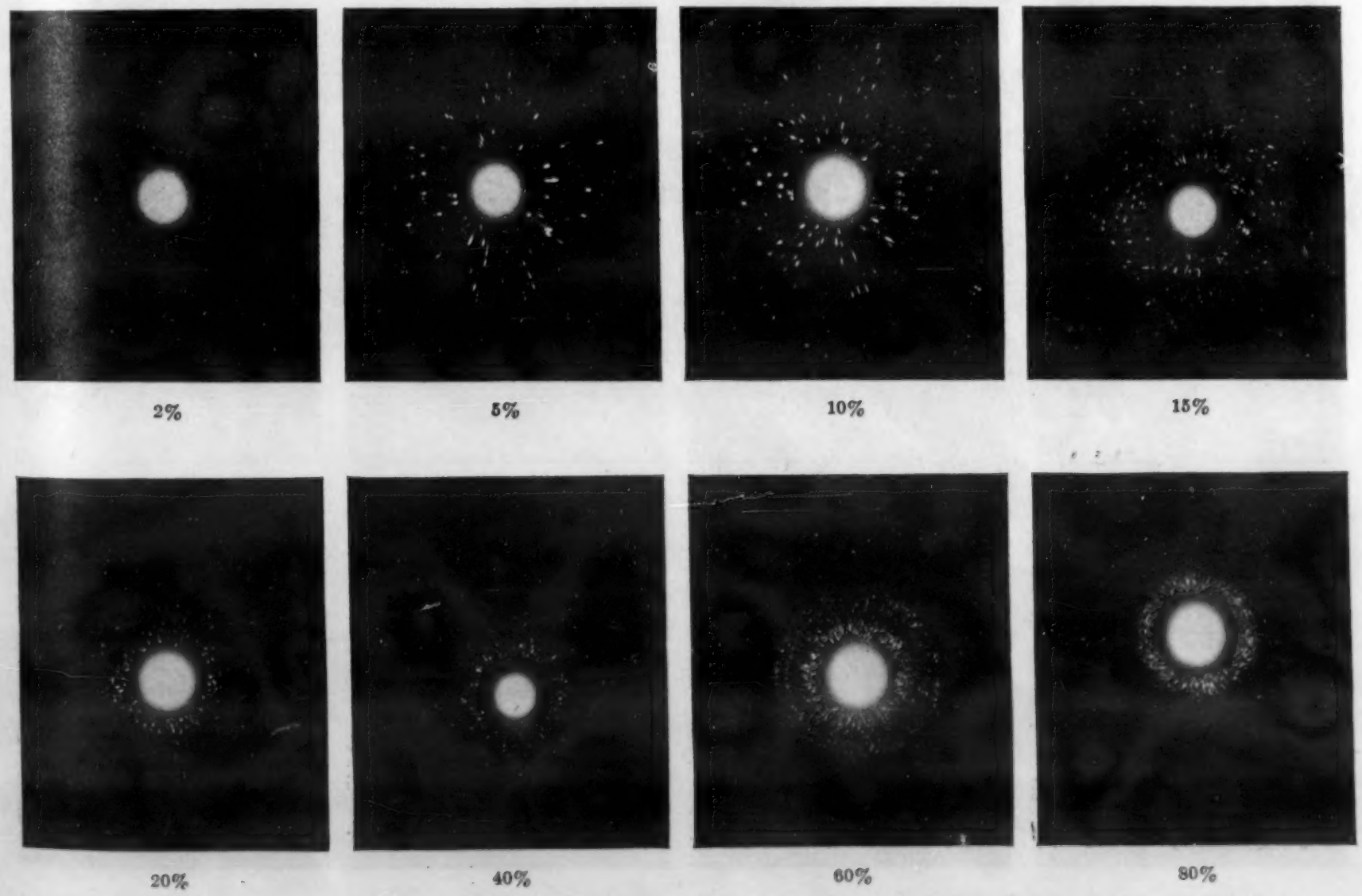


Figure 102—Effect of Annealing at 1200° F. on Low Carbon Sheet with Various Reductions by Cold-work. (Compare with Figure 103)

This is explained by twinned crystals in which (211) planes are twinning planes and lie in the direction of rolling.[23]

13. Effect of Carbon Content on Annealing.[22] X-ray studies of 0.06, 0.19 and 0.34% C steel wires drafted similarly and annealed at the same temperatures for the same length of time, prove that increasing carbon increases sluggishness in recrystallization, causes smaller but less distorted grains. In a similar way it has been possible to define in every case the temperature at which recrystallization begins after a given drafting or reduction in area by cold work, the temperature at which good annealing occurs, with removal of strain and directional properties due to original cold work, the grain size resulting from a given treatment, etc.

14. Effect of Grain Size on Plastic Deformation.[22] With ordinary low carbon basic open hearth steel wire, a large-grained sample may be drawn as much as 15% without suffering complete grain fragmentation or noticeable preferred orientation, whereas the fine-grained sample will show on its diffraction pattern definite fibering with only 5% reduction. These facts are shown in Figure 100.

15. Non-Uniformity of Production.[22] Many examples of this might be presented. In Figure 101 are shown the patterns for four samples of Bessemer steel and from the same continuous mill, selected from various coils. The differences require no comment.

16. The Relation between Reduction, Temperature of Annealing and Structure.[22] Two beautful series of patterns are reproduced. Figure 102 is for a constant annealing temperature of 1200° F. with successive reduction of low carbon sheet of 2, 5, 10, 15, 20, 40, 60 and 80%. Figure 103 is for 1500° F. temperature of annealing for the same specimens. These patterns constitute a splendid standard. The most marked effect is the difference between the temperatures of 1200 and 1500° on the specimen reduced in cross section area by 2%. At the lower temperature no recrystallization occurs while at the higher so great is the change that only a single grain of iron is in the beam.

17. The Examination of Very Large Specimens by the Back Reflection Method. In practically all of the examples cited in this entire paper, the X-ray diffraction patterns have been made by transmission through the specimens carefully prepared by etching so as to introduce no spurious effects. But in industrial practice it is frequently desired to know the ultimate crystalline condition of a finished product or of a large specimen which cannot be cut up. For example, in steel rails and in very large steel structures such as oil stills where sound structure and freedom from strain is so essential for safety at high temperatures and pressures, such an examination of a finished unit before installation would be invaluable. One method would, of course, consist in making hollow borings, with subsequent welding of the holes. In Figure 104 is shown the patterns for such borings from a forty-foot still. However, the writer has deemed it advisable to try and develop a method in which the X-ray beam may be reflected from the surface. The method involving a grazing angle of incidence as in Figure 32, with such an apparatus as that shown in Figure 28, Part II, is well known and has been frequently used for fairly small specimens. Utilizing the usual equipment, however, it is necessary to reflect straight back from the surface of very large specimens as shown in Figure 105. In this case, therefore, the photographic film is mounted *around* the pinhole, and registers the patterns of rays diffracted directly back from the surface. A typical pattern from a steel rail specimen is shown in Figure 106. The concentric pairs of rings seem at first sight to be very familiar until it is noticed that the less intense line is inside of the stronger line of each pair. If these pairs represent resolution of the Kα-doublet of molybdenum, then in ordinary powder diffraction films, of course, the stronger Kα_1 line comes inside the weaker Kα_2. This apparent reversal is, of course, readily explained by a consideration of Figure 107. The photographic plate is at ACB. If a cylindrical film, as in the Debye-Scherrer method, were placed coaxial with the

[23] N. P. Goss, *Trans. A. S. S. T.*, **1929**.

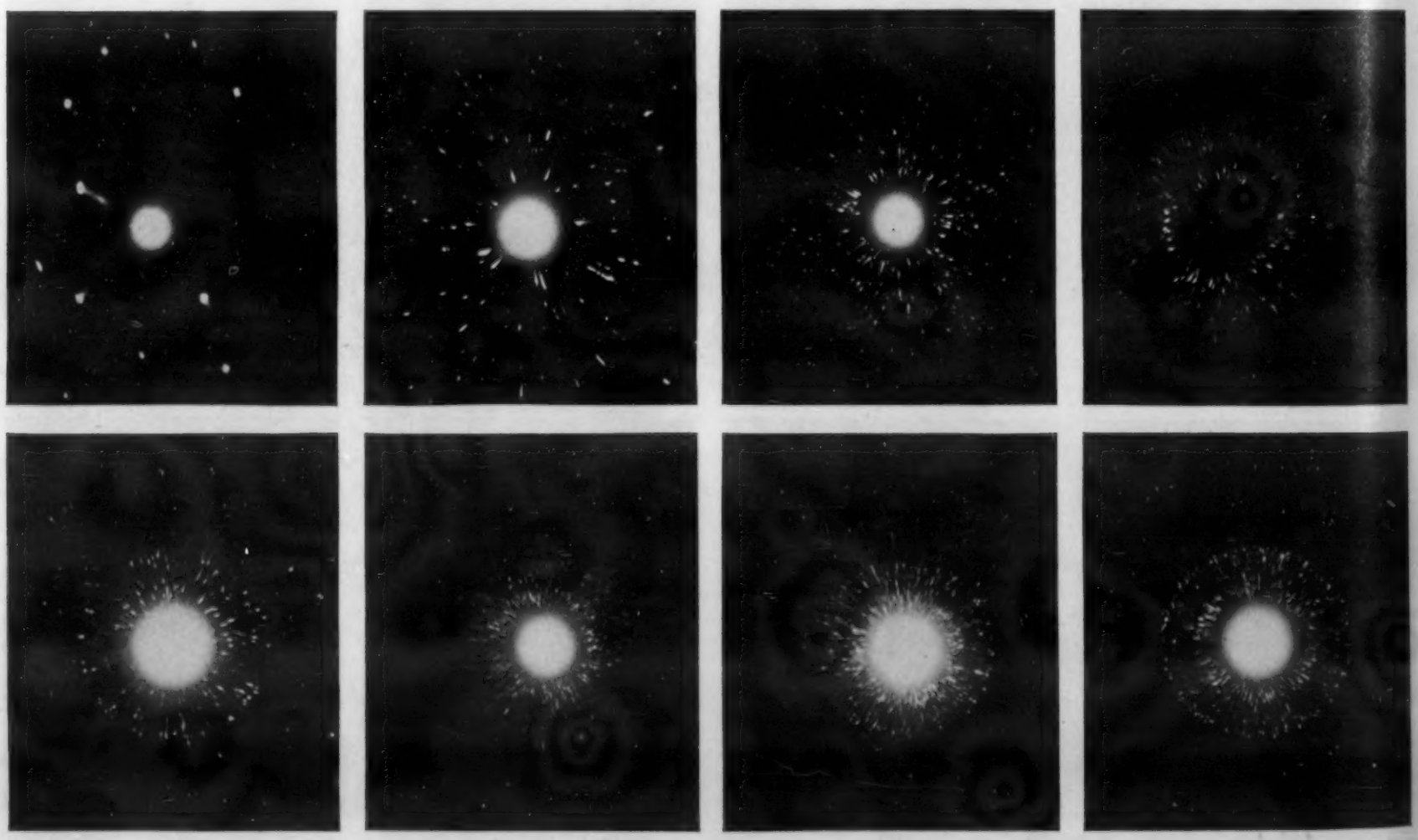


Figure 103—Effect of Annealing at 1500° F. on Low Carbon Sheet with Various Reductions (Same Order as in Figure 102)

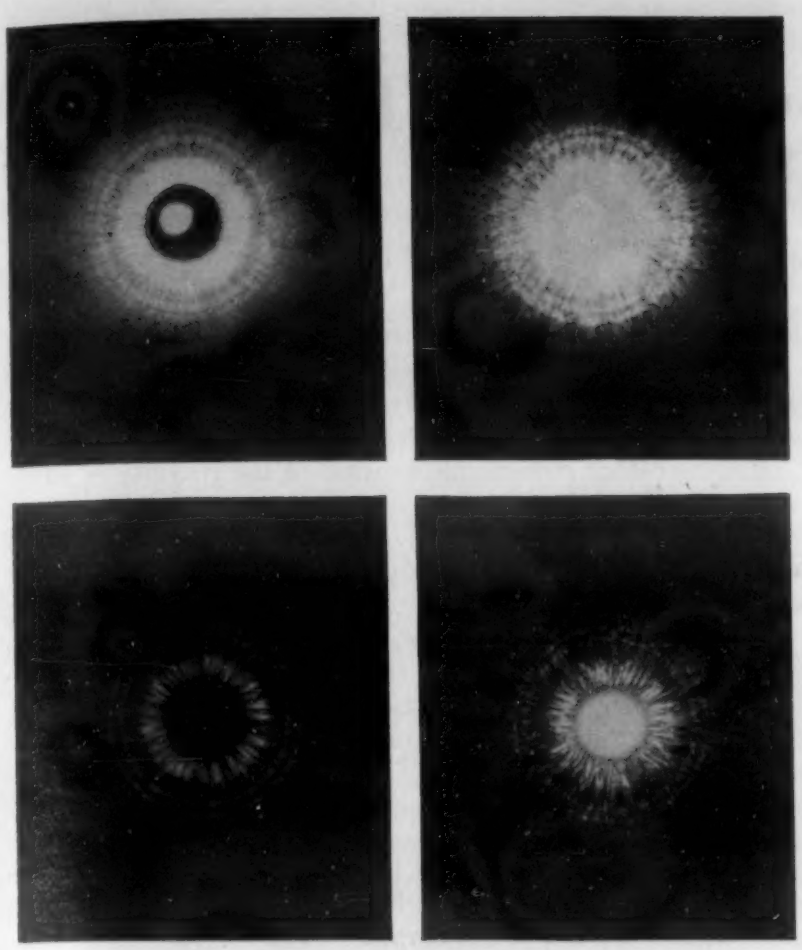


Figure 104—Patterns for Borings from Very Large Steel Oil Still as Tests for Uniformity of Structure

specimen, the primary beam passing through the specimen would strike the film at the top of the circle and the diffraction lines would appear as shown. The pattern in Figure 106 is, therefore, to be read from the *outside in* towards the center, rather than from the center, as would be the case if the film were placed on the opposite side of the circle. These diffraction circles correspond, therefore, to lines appearing at the very end of usual spectra and hence to planes of relatively high indices. The analysis is as follows, the distance from sample to film being 3.5 cm.:

Radius of Ring	ϕ	θ	Sin θ	$h^2+k^2+l^2$	hkl Indices	d_{hkl}
1.475	22° 50′	78° 35′	0.98021	62	3 7 2 5 6 1	0.363 A. U.
3.25	42° 52′	68° 34′	0.9308	56	6 4 2	0.383
3.90	48° 6′	65° 57′	0.9132	54	3 6 3 5 5 2	0.391

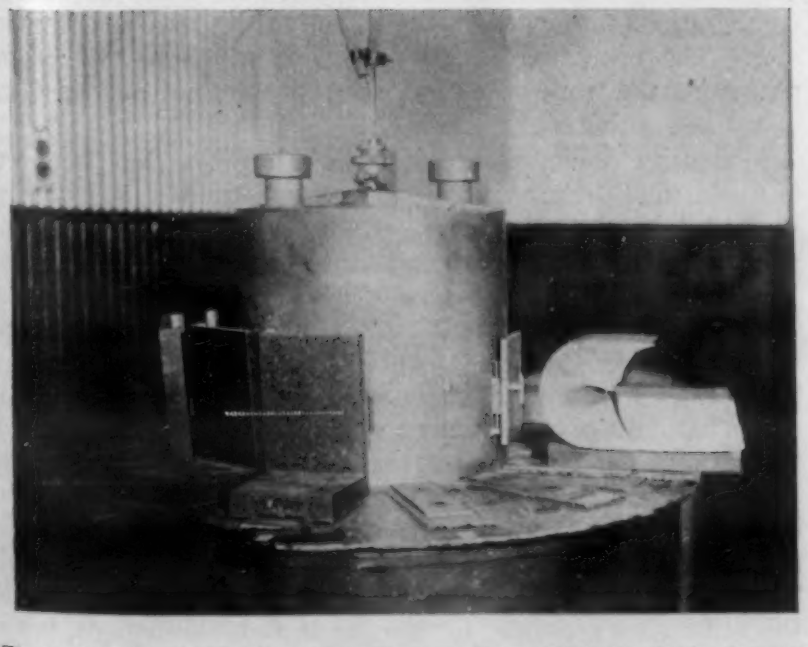


Figure 105—Experimental Arrangement on General Electric Diffraction Apparatus for Back Reflection Method

Figure 106—Back Reflection Pattern from Steel Rail

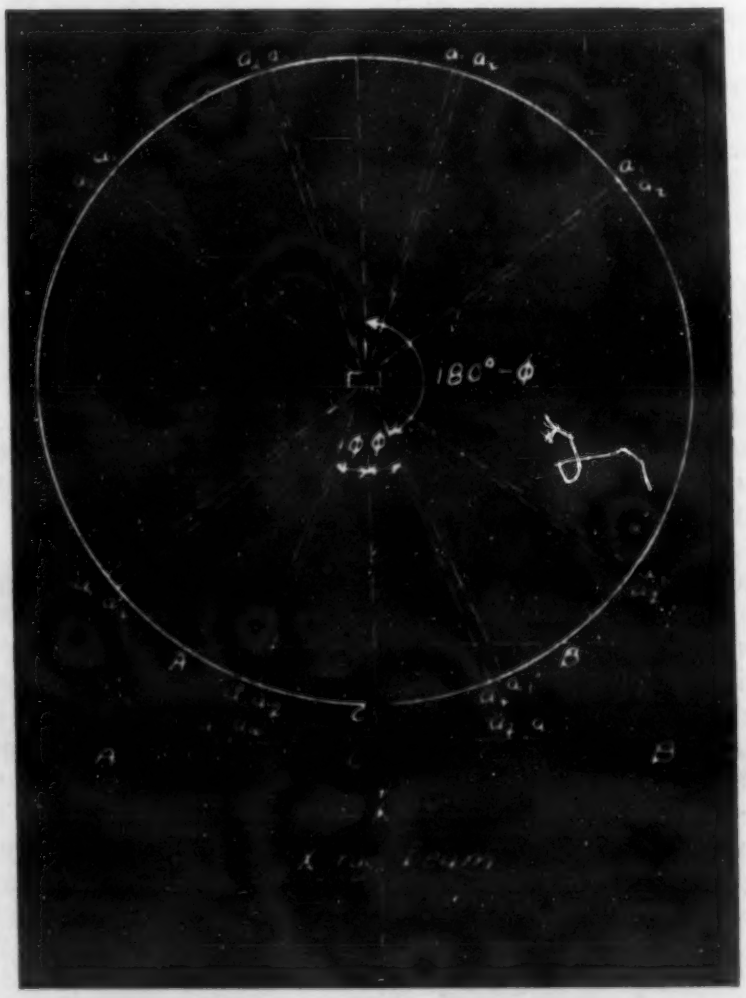


Figure 107—Diagram Explaining Diffraction Interferences on Film in Back Reflection

The method has the disadvantage, of course, that long exposure of several days is required to develop sufficient intensity for these diffraction effects from sparsely populated but closely spaced planes. However, large specimens of Armco iron with grains large enough to produce a spotted pattern by direct transmission also gave back reflection patterns with large spots. On account of the large resolutions of the Kα-doublet the method should be useful for evaluating spacings very accurately and for following small changes due to solid solution.

THE END

The Present Status of Cemented Tungsten Carbide Tools and Dies[1]

By Zay Jeffries[2]

I am leading this discussion as a representative of what might be called the cemented tungsten carbide industry in America. It is true that I am associated with one of the companies manufacturing and selling cemented tungsten carbide in America, namely, the Carboloy Company, Incorporated. There are, however, three other main channels of manufacture and distribution in the United States. Those are Thomas Prosser and Son, who are representative of Fried. Krupp, and they deal largely with imported tungsten carbide material made by the Krupp Company in Germany. Also, the Firth Sterling Steel Company manufactures and sells under the trade name "Diamondite" a similar material, and the Ludlum Steel Company deals in a similar material known as Straus Metal.

Before preparing this discussion, I communicated with the other representatives of the cemented tungsten carbide industry and obtained information from them as to their opinion of the present status of this industry in America, so that in a sense I have come before you to present a sort of composite picture for the whole industry. I will make no distinction, nor do I intend to imply that there is any fundamental difference between one brand of cemented tungsten carbide and another. The examples of performance to be reported later represent all of the brands.

The base metal of cemented tungsten carbide is tungsten. The hard component is tungsten carbide. It was known at least toward the middle or last third of the last century that ferro tungsten containing large percentages of carbon was excessively hard. The material, however, was also very brittle. Moissan, about 1898, produced in the electric furnace from tungsten oxide and carbon a material which he described as a carbide of tungsten and he reported that it was very hard. There were no common methods for determining hardness in those days except the scratch method, but the hardness was sufficient to attract Moissan's attention.

About 1904, Just and Hanemann in Budapest invented the squirted, or pressed tungsten lamp filament. In the process of making the filament they produced, in one stage, tungsten containing a small amount of carbon. Such filaments were so brittle and fragile that it seemed doubtful whether they would be commercial. In fact, as little as one-tenth to twenty-five hundredths of one percent carbon in such filaments rendered them not only brittle, hot and cold, but rendered them so fragile that a large percentage were broken merely by handling. The tungsten lamp filament industry, therefore, has been engaged in a battle against carbon from about 1904 until the present time. Even now, at times, carbonaceous material gets into the lamp and a little tungsten carbide forms at the grain boundaries of the tungsten near the point where the filament is joined to the leading-in wire. Under such conditions the tungsten becomes so brittle and fragile that a slight jar of the lamp breaks the filament.

Also in one of the processes of treating tungsten wire, the filament is heated to a temperature around 1200 degrees Centigrade, usually in an atmosphere of hydrogen. It was early learned that if the atmosphere were changed to a hydrocarbon atmosphere, say, by introducing a little kerosene or alcohol or gas, that within a few seconds the filament became so brittle and fragile that it could be broken to pieces in the fingers. This resulted, notwithstanding the fact that the filament before the treatment had a tensile strength of 600,000 pounds per square inch, and was quite ductile. The percentage of carbon required to produce this bad effect in tungsten was so small at times that it was difficult to detect it by chemical analysis.

It seems rather remarkable because of the fragility of tungsten containing a little carbon or fused tungsten carbide that the material which we are to discuss could contain from 85 to 95 percent of tungsten carbide and be sufficiently tough for cutting tool purposes.

The creation of this material represents a new metallurgy. The old metallurgy, especially the tool metallurgy, was essentially one of fusion and either use of the tool in the cast condition, with or without heat-treatment, or the use of the tool after forging plus heat-treatment. The present cemented tungsten carbide is produced by first manufacturing a very fine powder of tungsten carbide. The fine powder is then mixed with metallic cobalt. The mixture is then ball-milled, the action causing the cobalt to be smeared over the surface of the minute microscopic particles of the carbide. The mixture, after ball-milling, is then pressed into any desired shape and size. It may be partially sintered, then by heating to a low temperature in which condition it can be handled without breaking, and can be easily shaped with a steel tool. It is not really machinable in the sense that the metal can be cut by an ordinary tool, but partially sintered powder can be removed with ease.

The final sintering is done in an electric furnace with a hydrogen atmosphere at a brilliant white heat. This is the true cementing operation and cobalt is the cementing material. It is known that the cobalt takes up a little of the tungsten carbide in the process, but essentially the finished product consists of minute particles of tungsten carbide cemented together with cobalt or with cobalt containing some tungsten and carbon.

This material was developed in Germany by the Osram Lamp Works, Berlin, and the two men who are given the major credit for the development are Baumhauer and Shroter.

The development was first made for wire-drawing dies. The dies were to be used for drawing tungsten and molybdenum at elevated temperatures. Dr. Hoyt of the Research Laboratory of the General Electric Company in Schenectady started development work several years ago along the lines originally suggested by Baumhauer and Shroter. He made additional contributions to the development, and others have contributed also. The cemented tungsten carbide of to-day, therefore, represents the work of a good many people, not only in Germany, but in this country as well.

In density cemented tungsten carbide ranges, say, between fourteen and fifteen, sometimes lower, sometimes a little higher, so that it is relatively dense. Its hardness is difficult to appraise. It has a very high resistance to abrasion. Its resistance to indentation is relatively less than one might expect from its resistance to abrasion. The tungsten carbide itself has a hardness about comparable to sapphire or corundum. The scratch hardness of the cemented tungsten carbide is equal to the hardness of the hardest constituent, hence is equal to the hardness of the tungsten carbide. The indentation is made easier by the presence of the cobalt and hence the indentation hardness is relatively low as compared with the scratch hardness and as compared with the wear resistance of the material. The ordinary Rockwell hardness measurement on the C scale will not suffice generally for the hardness measurement, but a smaller load is used, and a special hardness scale (the A scale)

[1] Slightly condensed from the talk given before the Machine Shop Practice Division of the American Society of Mechanical Engineers, at Cleveland, Ohio, October 1, 1929.

[2] Consulting Engineer, Aluminum Company of America.

is used for these materials. Other devices, such as the Vickers Machine, and the Monotron, as well as the Rockwell can be used to evaluate the indentation hardness. There is no test for wear resistance equal to the service of tools in use, so that the appraisal of that factor is pretty much left to the user.

Whereas high speed steel requires a special heat-treatment to develop its hardness, cemented tungsten carbide is fully hard after cooling to room temperature from the high temperature sintering operation. It cannot be softened by heat-treatment alone. It can be reheated to a very high temperature and cooled either rapidly or slowly and it is still hard. Its red hardness surpasses that of any other metallic substance used in the tool industry.

No one knows just how hard it is at the high temperature, nor at what rate its hardness decreases at the higher temperatures. At any rate, it appears that temperatures which are ordinarily reached even in relatively severe industrial operations are not high enough to materially affect the red hardness of cemented tungsten carbide.

There are several ways of making cemented tungsten carbide and there are two or three different grades available to the trade. These grades differ both in composition and in treatment during preparation. They differ in physical properties as well. One of the grades contains about 87 percent of tungsten carbide and 13 percent of cobalt. This grade is tough, having at times a calculated tensile strength, as determined by the transverse test of 300,000 pounds per square inch. It has a high compressive strength, one determination being 540,000 pounds per square inch, the highest of any material which has been tested in our laboratory. Another grade contains about 6 percent of cobalt. It is somewhat harder as measured by the indentation test and considerably harder as measured by the abrasion, or wear test, and not so strong as measured by the transverse breaking test.

The industry is so new that the multiplication of grades has not reached the public. It is possible, however, by slight changes in composition and in methods of manufacture to produce quite a range of properties, and it seems practically certain that as time goes on industry itself will select from these possibilities what best suits its own purposes.

Cemented tungsten carbide is offered to the trade at a relatively high price. It is, in round numbers, $450 per pound. That, of course, is more than the material will cost in the future, and it is a price which none of us expect will be maintained in the industry. On the other hand, the industry is in the process of development, and development costs a great deal of money.

The first people to make investment in cemented tungsten carbide were those who carried on investigations and researches leading to its invention. The next group were the companies commercially exploiting the material. The next group was the machine tool builders.

The machine tool builders have already put some hundreds of thousands of dollars into the development of machines which will have sufficient power for, and be otherwise adapted to the use of cemented tungsten carbide, but before they did that, other groups put a considerable amount of money into researches on the nature of the material itself, on how to make it and on how to use it. I cannot speak for the other groups, but the Carboloy Company is still spending money faster than it receives it.

In spite of the present price, in most applications we find that the user of the material employs it at a distinct saving to himself.

Being a high-priced material, cemented tungsten carbide is utilized by the insertion of a tip on a shank of a cheaper material, usually some grade of steel. This has given rise to what is known as the tipping problem. Tipping has been taken care of in a number of ways. The art of tipping may not be all that is desired at the present time, and improvements can be expected in the future, but it has been found possible to put the cemented tungsten carbide tips on steel shanks by copper brazing in an atmosphere of hydrogen, with satisfactory results in most cases. There seems to be a preference for the welded tip for larger tools. The welding is attended by the hazard of cracking the cemented tungsten carbide itself, but when properly manipulated this hazard can be overcome. Both the welded tips and the brazed tips have been found satisfactory in service. Not a sufficient number of people throughout the industry are conversant with the art of tipping, to distribute this to the industry haphazardly. On the other hand, some of the industrial companies have worked on this problem and are in a position to make their own tools. If a concern has only a little tipping to do, it is probably best to permit one of the companies specializing in putting on these tips to make the tools. All of the companies exploiting this material in America have organizations for doing this work, and the organizations, of course, are at your service. You have at the present time, therefore, two channels for acquiring a tool: one is to design the tool and order it tipped and ground, and the other is to buy the material and make the tools yourselves. There may be some advantage to the exploiters of this material in the latter method because companies putting on their own tips are satisfied with very much poorer jobs of tipping than when buying finished tools. If the cemented tungsten carbide cracks during the tipping or grinding operation in one's own plant he uses the tool anyway, and finds sometimes it lasts as long as if the crack were not there, but if he orders a finished tool, he rightfully demands that it shall be free from defects.

The next problem in connection with the manufacture of a tool is grinding, and without attempting to go into detail I might say that there are several companies in the United States that sell grinding wheels suitable for the grinding of these materials. The base material for these grinding wheels is in most cases, and perhaps all cases, silicon carbide, known as carborundum, or crystolon. Whereas, six or eight months ago the matter of grinding these tools was a serious one, at the present time, it may be said that that problem has at least passed the temporary crisis. There are certain precautions which the user will soon learn, but the information can be obtained from any of the companies exploiting this material and from the grinding wheel companies.

Now, as to the uses of cemented tungsten carbide. The material—cemented tungsten carbide—has a much broader application than the use of tools in machining.

There seems to be a tremendous field for wire-drawing dies, or, in general, drawing dies. I will give you two examples, one drawing screen wire of .0108 inches in diameter, the other drawing larger wire, a little over $^1/_{10}$ of an inch in diameter. The reason I give the two cases is that in one field the competing material is the diamond die and in the other the competing material is the chilled iron die. In the first case, the cemented tungsten carbide die drew 57,800,000 feet of wire, .0108 inches in diameter, with a wear of $^7/_{10,000}$ of an inch in diameter. At this size the performance was approximately equivalent to that of a diamond die, but with more cuts possible in the cemented tungsten carbide. The over-all improvement in cost on a performance basis over diamond was 6 to 1. The second example is the drawing of steel wire, .105 inches in diameter. Over a 12-day period there were 264 chilled iron dies used in this line. Over the same period one cemented tungsten carbide die performed without going off size. We had, therefore, one cemented tungsten carbide die taking the place of 264 chilled iron dies. On the basis of die cost alone the cemented tungsten carbide was cheaper than the chilled iron by a ratio of 36.6 to 18. In addition to that, 20 percent more wire was produced during the period on the one cemented tungsten carbide than was produced on the 264 iron dies. Also, the cemented tungsten carbide dies are being used for hot drawing of tungsten and molybdenum and we perhaps will hear more in the future about the use in hot drawing of other materials.

The material is also usable as a blanking die and in particular in the General Electric Company in punching transformer discs. It is found that the cemented tungsten carbide blanking discs

produce a material free from burrs. In blanking 200,000 the first one and the last one appeared to be just alike.

Cemented tungsten carbide is used for cutting materials which no other metallic material has been able to cut. In that sense cemented tungsten carbide is opening up a new field for machining. Machining is only one method of shaping articles. Machining has been used to a much greater extent in shaping metals than it has for everything else combined. Cemented tungsten carbide can machine glass, it can machine porcelain, it can machine compounds used in the electrical industry such as Micalex, and it can machine ivory and things of that sort. It machines various non-metallic materials known as the fibrous materials which are abrasive, those containing mixtures of asbestos and other materials used in brake-linings and floor boards and it machines molded products of the bakelite type. In some instances, it replaces diamond in those operations, but in other instances, it makes possible the machining of parts which, heretofore, could not be shaped economically by machines with any known tool.

The material is also used for cutting rock. It can be used to saw rock, replacing the old-time saw teeth of other materials with cemented tungsten carbide. It is also used in gages, knife edges and blast nozzles, etc.

In the machining industry I am going to mention a few examples of tool replacement. It should be obvious that when a new tool material with the capabilities of cemented tungsten carbide is made available, existing machines might not be able to take full advantage of it. Nevertheless, the machines which have been made during the past five, ten or even fifteen years, have been adapted, in a way, to use this material, and whereas one would not expect a maximum performance from these machines, it is interesting to see what performance is obtained.

In turning a laminated armature by the old tooling methods and tools the performance was one armature per grind. With cemented tungsten carbide forty armatures were turned per grind. The speed was 700 feet per minute, hand feed, and one sixty-fourth inch cut.

In a commutator, rough and finish turning, the old record with the existing tools was 150 pieces per grind; with cemented tungsten carbide it was 30,000 pieces per grind.

Another example is a cut-off tool; the old performance was 100 cuts per grind and cemented tungsten carbide made 15,000 cuts per grind.

In profiling 1020 S. A. E. steel at very high speed the old practice was 60 pieces between grinds, and with cemented tungsten carbide it was 25,000 pieces.

Ivory has been turned at 6000 feet per minute, hand feed, with only a skin cut, with a result about the same as that obtained with a diamond tool.

In boring main transmission bearing holes in cast iron, $4^1/_2$ inches in diameter, 100 to 125 pieces per grind with the old tools was considered good, but 950 per grind were machined with cemented tungsten carbide.

In finishing boring of a bronze bushing with a tolerance of $^5/_{10.000}$ of an inch, the old record with existing tools was 150 pieces per grind, and with cemented tungsten carbide, 7000. There was, with the cemented tungsten carbide, only 5 percent of the machine scrap that was obtained with the other tools. That is a very significant point, I think; namely, that in machining to close tolerances the longer the life of the tool the less the machine scrap.

In reaming a malleable iron differential carrier with $3^3/_4$-inch diameter hole, at 70 feet per minute with a 64th-inch cut and hand feed, there was, with the old tools one to two adjustments per day, and with cemented tungsten carbide one tool had been running for eleven weeks without changing, when this report was received.

With a 16-inch diameter circular saw having insert teeth, the increase in speed was from 900 revolutions to 1600 revolutions per minute. Cutting artificial floor board material made of magnesia, asbestos and wood shavings, the steel saw cut 80 feet of board between grinds and cemented tungsten carbide 1520; this represents a 78 percent increase in speed, and 1800 percent increase in footage between grinds.

It may be said that cemented tungsten carbide received its initial publicity in the United States approximately one year ago. It is true that some of the tools from the Krupp works had been sold prior to that time. It is an interesting point here to note that fifteen months ago one tool was sold to a large manufacturer in the United States and that tool is still working, and in fifteen months it has replaced 2450 pounds of the type of tool material which was being used at the time this cemented tungsten carbide tool was introduced. But generally speaking, about one year ago, the whole country became conscious that there was such a material as cemented tungsten carbide. Naturally, the machine tool builders had to make tests of their own to warrant their own expenditures in developing machines to better fit the properties of cemented tungsten carbide, and I think it is paying them a great tribute to see what they have accomplished in this short time.

With so much accomplished in one year, can we not look confidently forward to the future toward a still more rapid development?

Just a brief statement about the commercial situation. A year ago, there was a clamor for tools, and for months the imported material and the material made in this country was not sufficient in quantity, or could not be made into tools rapidly enough to fill this demand. The first interest was naturally for trial purposes, and there was no great demand from any one source. The expense of trying to comply with such a demand, of course, was tremendous, and also it put quite a tax on the organizations. But all of the organizations fought with that situation until about the middle of the past summer. Since then the delivery dates on most ordinary tools have been short. The same condition obtains at the present time. There are, however, a number of tools desired by the industry which it has not been found practical or expedient to make at the present time, such as very large dies for drawing rod and tubing, but that demand will be taken care of in the not distant future.

The various companies for the past three months have been in a position to supply ordinary tools faster than the industry has desired them. Within the last few weeks, however, the demand has increased to a point which is taxing the producing organizations.

The advent of high speed steel was a great thing for not only the steel industry, but for all industry. It was a great thing for mankind. It has played a major role in our economic civilization, and it has done, perhaps, more than any other one development in the last twenty-five years to help make men economically independent, and to help make the expenditure of a given amount of human energy produce more of the necessities and luxuries of life. Its advent, however, did not reduce the amount of carbon steel tools used. There are apparently to-day being made every year more carbon steel tools than were made in the year 1905. I am not picking out 1905 as a depression year, but the year when high speed steel began to have a real effect on production. In the same way we do not anticipate that cemented tungsten carbide, even though it be sold much more cheaply than it is to-day, will eliminate high speed or carbon steel tools. I strongly suspect that in, say 1935, there will be more high speed steel made per year than in 1929. Furthermore, we do not regard this material as a cure-all for everything in the tool industry. Some applications have met with very indifferent success; some attempted applications can be branded at the present time as absolute failures.

We do not know where this material will lead us, especially from the standpoint of tool substitutions. It seems to me, however, that we have gone far enough so that we can say definitely that cemented tungsten carbide is destined, not only to have a definite place in the future of industry, but a most important place; that it will be used in large quantities and

for a great variety of purposes in the future there can be no question. One of the results is going to be the enhancement of the high speed steel and stellite era toward greater economic benefits for mankind. It seems reasonable that the material offers the possibility of increasing, on the average, production in machine shops to the extent of 20 percent, or will make possible the production in five days what now takes six. If so, it must benefit all of the people, because machined goods will cost less. It will benefit the metal industries because more metal can be used and more metal will be put into shavings and turnings than is done at the present time. Machining enters the field of competition in the shaping of metals with an improved tool, hence it is only natural that a larger percentage of the shaping of materials will be done by machining.

In discussion it was brought out that so far tungsten carbide tools have shown little promise for taking fine finishing cuts on steel. The tools work better on a cut of over 15 thousandths at very high speed than on a light cut of say 3 thousandths. It seems to be best to make the tool do a lot of work.

In cutting cast iron and malleable iron, some trouble was met until rigid machine tool construction was used, and the tungsten carbide tools run at extremely high speed.

Note on the Possibility of Enlargement by X-rays*

Frederick Sillers, Jr.[1]

In the course of some development work along the line of high voltage X-ray spectrography the writer encountered a phenomenon which at once indicated the possibility of enlarging the image of an object in radiography. This was the obtaining of an image of the target of the X-ray tube through a small "pin-hole" in a lead sheet. The writer accordingly introduced an object in the path of the rays emerging from the pin-hole and, after proper adjustment of the interspatial distances, obtained an image of the object twice natural size. Figure 1 gives such a radiograph in which the object was a letter "L" cut from a piece of terne-coated sheet steel. The original letter was 1/8 inch in height; its image is 1/4 inch in height. As might be inferred from the above, the enlargement could have been varied at will. For example, a specimen 1/32 inch high placed nearer the pin-hole could have been conveniently enlarged to a value in the neighborhood of 15 times natural size. Smaller specimens could have been made to yield proportionately greater enlargements. The reason for this will be made clear later.

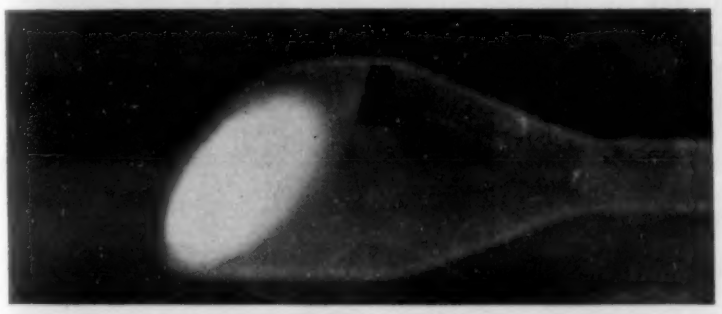


Figure 1—Radiograph of a Terne-Coated Steel Letter "L" Superimposed upon the Image of the Target of the X-ray Tube. Actual Size of Letter, 1/8 Inch; Radiographed Size, 1/4 Inch

Voltage: 163,000; Milliamperage: 5; Exposure time: 45 minutes; Pin-hole: 1/30 inch; Distance from target: 15 inches; Distance to film: 15 inches; Distance to specimen: 7 1/2 inches.

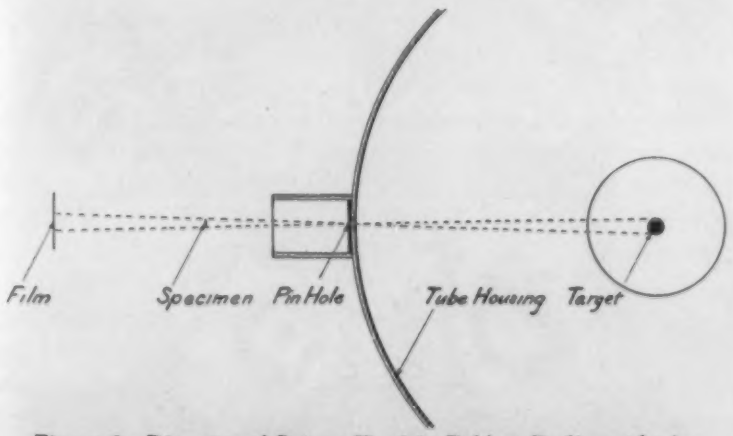
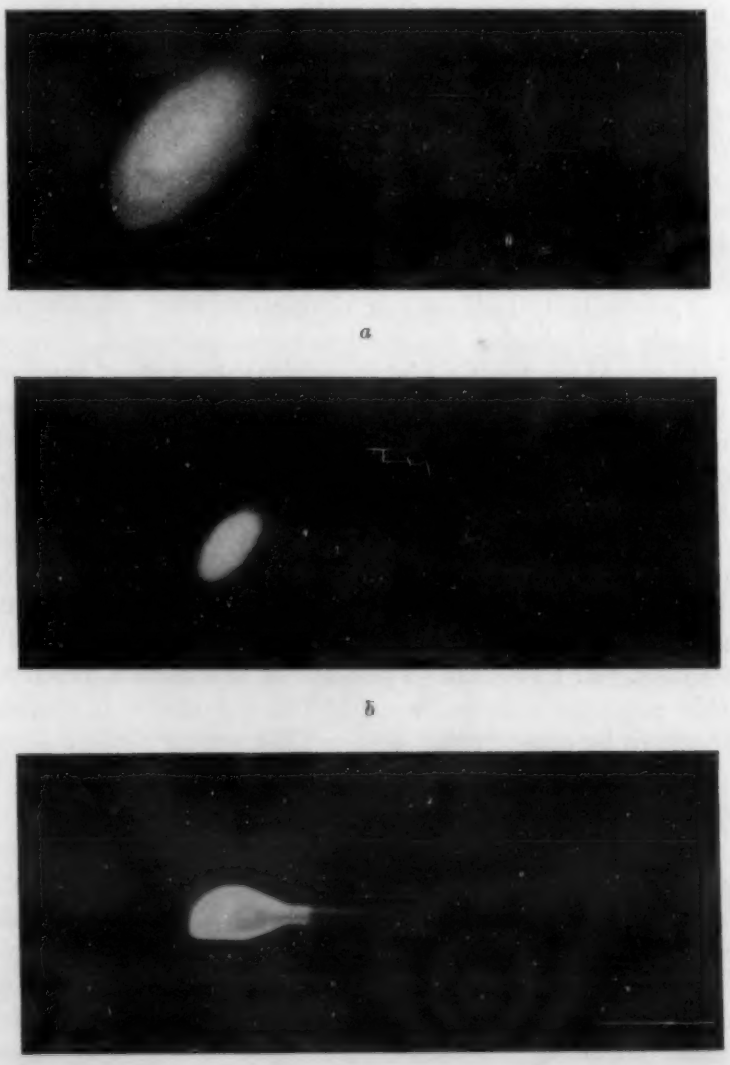


Figure 2—Diagram of Set-up Used in Taking Radiographs in Which Enlargement Is Obtained

Referring again to Figure 1 it will be noted that the image of the X-ray target serves as a background for the "L." The former is natural size due to the conditions of the exposure. Reference to Figure 2 will indicate the reason for this.

Figure 2 is a schematic drawing of the set-up used. It will be recognized as being identical in principle with the familiar "pin-hole photograph" arrangement of ordinary photography. In the present case the light source is the target of an X-ray tube; the light, X-rays; and the pin-hole, a small hole in a lead sheet.

In obtaining the radiograph shown in Figure 1, the target to pin-hole distance was made to equal the pin-hole to film distance. The specimen was placed mid-way between the pin-hole and the film. Hence the image of the specimen was double size and the image of the target natural size.



a

b

c

Figure 3—Radiographs of the X-ray Target at Different Reductions

That the size of the target image may also be varied is illustrated in Figure 3 (*a*, *b* and *c*). These images constitute various reductions, but they might well have been enlargements if more space had been available in which to work.

(*Continued on page 236*)

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A New Automatic Metallographic Polishing Machine*

By S. Epstein[1] and John P. Buckley[2]

Introduction

Polishing metal specimens for microscopic examination is an art not easily learned. The usual college course in metallography seldom gives the student sufficient experience to acquire the necessary skill, and even after long experience metallographers will find themselves spending a great deal of time in rectifying poor polishing results or in trying out various modifications, generally minor ones, in their polishing procedure. Such modifications seem to have consisted mainly in fluctuations about a norm, for the polishing procedure followed by a majority of metallographers to-day is not much different from that in use ten, twenty or thirty years ago. Although there has been continual concern over polishing methods very little systematic study has been given to the subject since the early days of metallography. The Bureau has recently undertaken such a study, the object of which is to make thorough trials of the important variables in the procedure, such as abrasives, the matrix for the abrasives (i. e., cloths, metal laps, pitch polishers, etc.), speeds, pressures, etc. It is hoped that a recommended practice for metallographic polishing can be developed from the results of this study. Later, an inquiry into the theoretical matters involved may perhaps be desirable.

It was realized that, in the study of the polishing procedure, it would be necessary to eliminate, as far as possible, all irregularities and errors due to the personal equation such as would inevitably arise with the use of hand-polishing. This desired condition would be obtained by means of a properly devised automatic polishing machine. Moreover, it was apparent that the building of a successful automatic polishing machine would, aside from its use in this study, be a sufficient end in itself. Hand-polishing not only requires skill hard to attain, especially where a high quality polish is desired, but also is exceedingly tedious and time-consuming. Every effort was made in designing the machine to construct it along such lines as would render it a highly serviceable piece of equipment in any metallographic laboratory with manifest advantages over hand-polishing. It should be stated here that several models of automatic polishing machines were available in the market when this work was begun but for various reasons they were regarded as not being fully suitable and the development of a new model was preferred. Such a machine has been developed, and it has proved very satisfactory after several months' operation under routine laboratory conditions. It was considered advisable to publish at this time a description of this machine without waiting for the study of polishing methods to be completed.

General Requirements

In optical glass polishing automatic methods are practically universal and it might seem, therefore, that both the optical methods and machines could be adapted to metallographic work. However, there are radical differences between optical and metallographic polishing. In optical polishing, and this applies also to such operations as gage lapping where mechanical polishing is very successfully used, the material polished is always very hard, no special precautions have to be taken to prevent any flow or disturbance of the polished surface, and the main consideration is the contour or the dimensions of the finished object. In metallographic polishing, on the other hand, most of the specimens are relatively soft, the contour of the surface is of secondary importance as only a rough approximation to optical planeness is required, and the essential thing is the quality of the finished surface which must be undisturbed, with all the constituents left in place and not covered or removed. It may be mentioned in passing that an optically ground and polished lens, for instance, is of considerable and permanent value, whereas ordinarily a polished metallographic specimen is of only momentary value usually being discarded once the microscopic examination is over.

Because of the above differences metallographic polishing has followed a different course from that of optical polishing. In optical polishing machines the work itself is usually moved over a slowly turning polisher and, in general, the speeds used are much slower than in metallographic polishing, especially during grinding where high speeds, of course, might cause cracking of the glass. The pressures are considerably greater in optical polishing since there is little concern over disturbing or flowing the surface. Toward the end of the operation, as the work makes optical contact with the polisher, the forces between them become quite large and considerable viscous flow probably occurs. Hard metallic laps and pitch polishers are generally used instead of cloth-covered disks, as in metallographic polishing, in order to get more accurate contours. Such comparatively hard backings for the abrasives would be of advantage in metallographic polishing in decreasing rounding at edges, relief-polishing of hard constituents and pitting about cracks and inclusions, which effects are mainly due to the soft and yielding nature of the polishing cloth. However, the difficulty with pitch and other such polishing disks is that with all metals except hardened steel the specimen becomes impregnated with the abrasive and a matted, instead of a polished, surface is obtained. Unless some way of lubricating the hard polishing disks is devised which will entirely obviate this, the use of cloth-covered disks with their attendant disadvantages will have to be continued.

It may be emphasized here that it seemed essential to put high quality workmanship and material into the construction of the polishing machine. In the average laboratory the importance of having a good polishing machine appears to have been neglected or not sufficiently recognized. This has undoubtedly resulted in a deplorable waste of time in metallographic work as well as in lowering the quality of such work. In reality, the polishing machine is almost as important a piece of apparatus as the microscope itself. Ordinarily, a great deal more of the metallographer's time is spent in polishing, etching and repolishing the specimens than in examining them under the microscope and photographing them.

In designing the automatic polishing machine, the underlying principles employed did not depart in any essential respects from those in everyday use in metallographic hand polishing. The purpose of securing a high quality polish at least equal, or superior if possible, to that obtained by hand methods was kept uppermost. It might be mentioned that Pulsifer[3] has described a more rapid method of preparing microsections, by alternate grinding and etching, in which method the basic idea is that the preparation of a highly polished surface is unnecessary for revealing the structure. Aside from the fact that his method is not applicable to the study of inclusions and saves time only for the soft metals and not for iron or steel, it may be questioned on broad grounds whether such a rough method should be recommended for general use. The possibility of errors in judgment in microscopic work is very great even with most painstaking preparation of specimens and after much experience, and it appears unwise, if only from the

* Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

[1] Associate metallurgist.

[2] Mechanical draughtsman.

[3] H. B. Pulsifer, "Structural Metallography," Chemical Publishing Co., Easton, Pa.

psychological standpoint, to advocate a method which for the sake of speed might seem to countenance carelessness and which might fail to instill the requisite pride in good-looking and accurate work.

Description of Machine

The details of the machine are given in Figures 1, 2, 3, 4 and 5. The machine consists essentially of a polishing disk mounted horizontally on a suitably designed table and a driving mechanism, actuated by an alternating current, variable speed motor of 300 to 1200 r. p. m., for rotating the disk at a speed of approximately 250 r. p. m.

The specimen to be polished is mounted in a metal ring, which will accommodate specimens up to $1^1/_4$ inches diameter and about $1^1/_2$ inches high. This specimen holder, containing the specimen, is *positively* held in an arm, through which it is geared to an eccentric gear attached at the top of a shaft passing vertically through the axis of the polishing disk (Figure 3), and is slowly moved back and forth (about 2 times a minute) along a radius of the turning disk. At the same time the specimen is slowly rotated so that the direction in which it is polished changes continually. This rotating movement was deemed essential to prevent pitting and the formation of "comet tails" at inclusions. An intermittent gear for halting the oscillation of the arm for a brief interval during which the specimen holder was rotated through approximately 90° was tried out, but this arrangement proved to be superfluous. Three arms are supplied to one polishing disk, which is nine inches in diameter, so that with one or more units (according to the number of polishing stages used) three times as many specimens as units employed can be polished at a time.

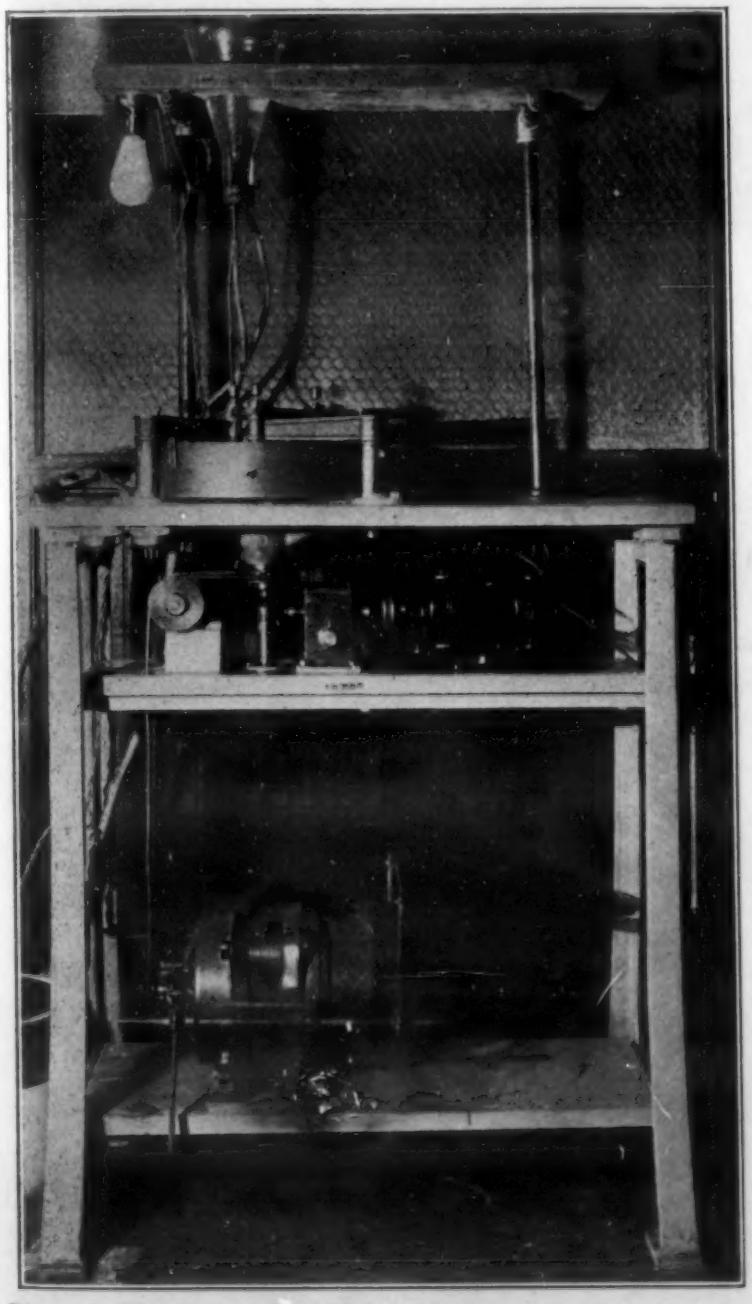

Figure 1—Side View of First Model of Automatic Polishing Machine

The shaft carrying the polishing disk is mounted in ball bearings to insure smooth working. Ample provision has been made to protect all bearings from abrasives and water. A belt drive, for connecting the driving mechanism to the motor, was chosen as being superior to a frictional drive, especially for this type of machine.

The abrasive may be continually supplied from a flask on a shelf placed above the polishing disk. The water containing the abrasive is agitated by an air stream, and the flow is regulated by a stop-cock. A brass rod "wiper" attached to the wall of the pan, within which the polishing disk is placed, and resting upon the rim of the disk has been found useful in preventing the clogging of the disk with abrasive by distributing it more evenly over the disk.

A most important part of the machine is the means of holding the specimen flat on the polishing disk and applying the necessary light pressure. This is very conveniently accomplished by a spring arrangement attached to the end of the arm. This is shown in Figure 5. Pressure is applied to the "back side" (that is, on the side opposite to the direction of rotation of the polishing disk) of the specimen holder by means of a yoke to which the spring is attached, resting upon a flange at the bottom of the holder. Additional pressure may be applied through a sufficiently weighted pin which bears on the center of the mounted specimen. Before the spring arrangement was installed the pressure was applied from overhead only through this pin. The polishing results then obtained were very unsatisfactory because of the rounding of the surface, deep scratching and slow polishing. The explanation seemed to be as follows: as the turning disk moves past the specimen a good deal of drag is set up between the "front side" and the cloth of the polishing disk. It is this frictional pressure which causes a specimen to fly out of the hand during hand-polishing. In polishing by hand one instinctively compensates for the tendency to dig in at the "front" by a slight pressure on the "back;" this keeps the specimen balanced and eliminates the frictional pull. If something similar is not done in mechanical polishing, the specimen holder will jam tightly against the prongs of the support in which it is held and thereby be pressed hard against the disk so that deep scratches are formed. At the same time the holder no longer rests flatly on the disk but is tilted slightly. Most of the polishing therefore takes place at the circumference of the specimen, appreciable time elapses until the center is touched, and a rounded surface is the final result. With the spring at the side, however, the frictional drag is successfully balanced and the above difficulties are avoided. The spring is adjusted so that pressure downward and inward may be applied, the latter pressure preventing cocking against the prongs of the support. The specimen

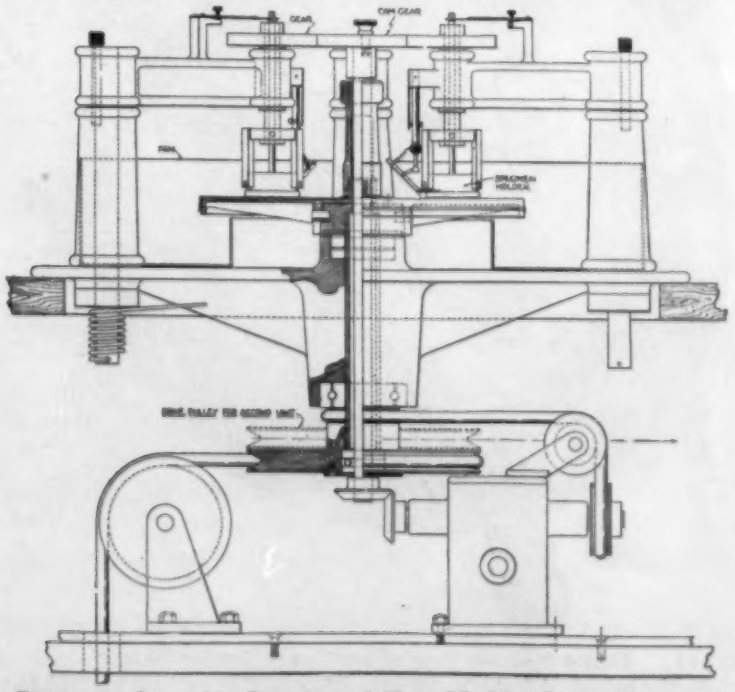

Figure 2—Assembly Drawing of New Model; Some Changes in Dimensions Were Made for Greater Convenience in Working. The Spring Arrangement Placed at the Side of the Specimen Holder for Balancing It during Polishing Is Shown

holder fits easily into the support and the spring is very readily adjusted in a few seconds for uniform and flat polishing.

In the first model of the machine one motor was used for driving the polishing disk and another for rotating the specimens. The reason for the use of two motors was that for the purpose of studying polishing methods it was desired to have independent control of the speed of turning of the polishing disk and the speed of rotation of the specimen. A revolution counter for the polishing disk was also attached. Figure 1 shows a side view of this machine, before the spring attachment to the specimen holder was adopted. Another machine provided with two polishing disks is now being built along essentially the same lines, but with slight changes in dimensions for greater convenience. One motor will drive the two polishing disks, the same motor also rotating the specimens. Figure 2 shows an assembly drawing of this machine for one polishing disk. Figure 4 shows the transmission for the two polishing disks. Each disk may, of course, be turned on or off independently of the other.

Mounting of Specimens

In hand-polishing specimens such as filaments, sheets or other odd shapes and small sizes usually are mounted, but in this type of machine all specimens must be mounted. The question, therefore, of a suitable mounting medium becomes a very important one. Of course, materials usually employed for this purpose such as the white metal alloys and litharge-glycerine cement may be used but these have decided disadvantages. They tend to smear and clog the polishing disk and may also scratch the specimen, but, above all, they seriously interfere with the subsequent etching of the specimen, since they are readily attacked by both acid and alkaline etching reagents.

In work recently done at the Bureau on dental alloys sulphur was found to be a very convenient mounting medium. It has a sufficiently low melting point (120° C.), quickly hardens after solidifying, is clean and is inert to acid etching solutions although it is attacked by alkaline sodium picrate and will disintegrate in the boiling solution of this reagent used for etching steel. However, the polished specimen is very readily knocked out of the surrounding sulphur without spoiling the surface and may then be etched without interference. A disadvantage of sulphur is that sometimes during the polishing it forms tiny pits on the surface of steel which may be mistaken for inclusions; it also tarnishes copper and its alloys. It has been stated that the latter effect may be overcome by adding about one percent of powdered graphite to the sulphur. A very useful precaution is to cut away the sulphur surrounding the specimen so that it does not come in contact with the polishing disk. This may be very readily done soon after the sulphur solidifies when it is comparatively soft. In mounting with sulphur the specimen and ring may first be ground flat and then laid face down on the glass side of discarded photographic plate. By previously moistening the plate with glycerine the specimen and ring will stick to the plate and come out level with each other after the sulphur solidifies; this will save subsequent grinding to obtain a level surface. A slight amount of glycerine left in the ring before pouring in the molten sulphur will lift the sulphur from the glass and thus minimize the amount of cutting away required to keep the sulphur out of contact with the polishing disk. In general, sulphur makes a very convenient mounting medium if the above-mentioned precautions are taken.

Condensation products of phenol, such as bakelite, have even better properties than sulphur. Bakelite is very hard, can be molded at about 150° C., and is practically inert in both acid and alkaline reagents. The difficulty is that it must be molded under pressure so that some additional equipment is required. However, this is not prohibitive as a very small press is sufficient, the molding pressure needed being only 2000 pounds per square inch. A small electric furnace for

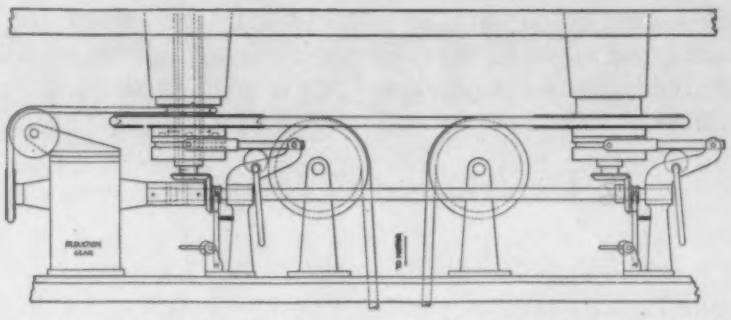

Figure 4—Transmission for Two Polishing Units Driven by One Motor

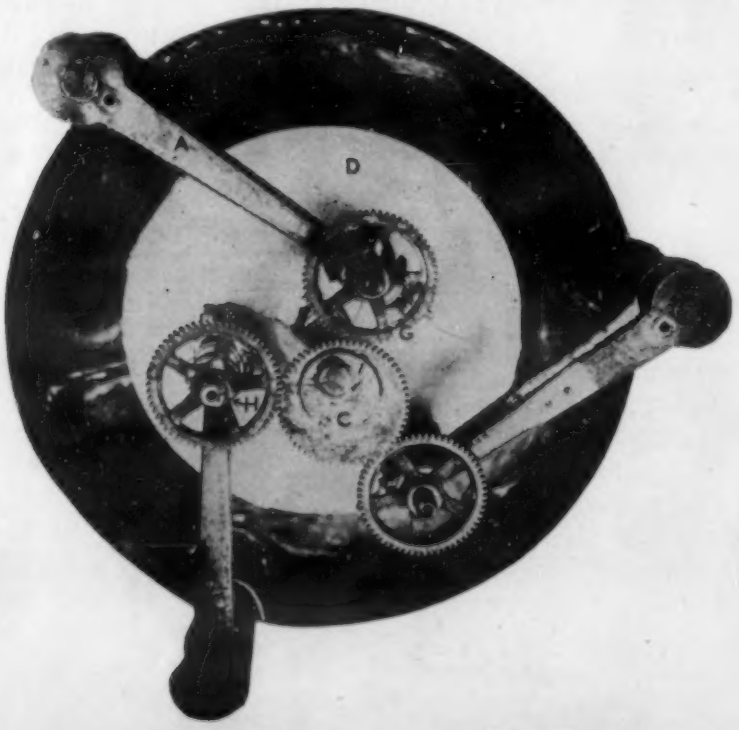

Figure 3—Plan View of the Top of the Machine
A, oscillating arm which carries the specimen and its holder; G, gear for rotating the specimen as it is moved across the polishing disc, D; C, cam gear by which the oscillation of the arms is brought about. Through the hole, H, a weighted pin may be inserted so as to rest upon the specimen.

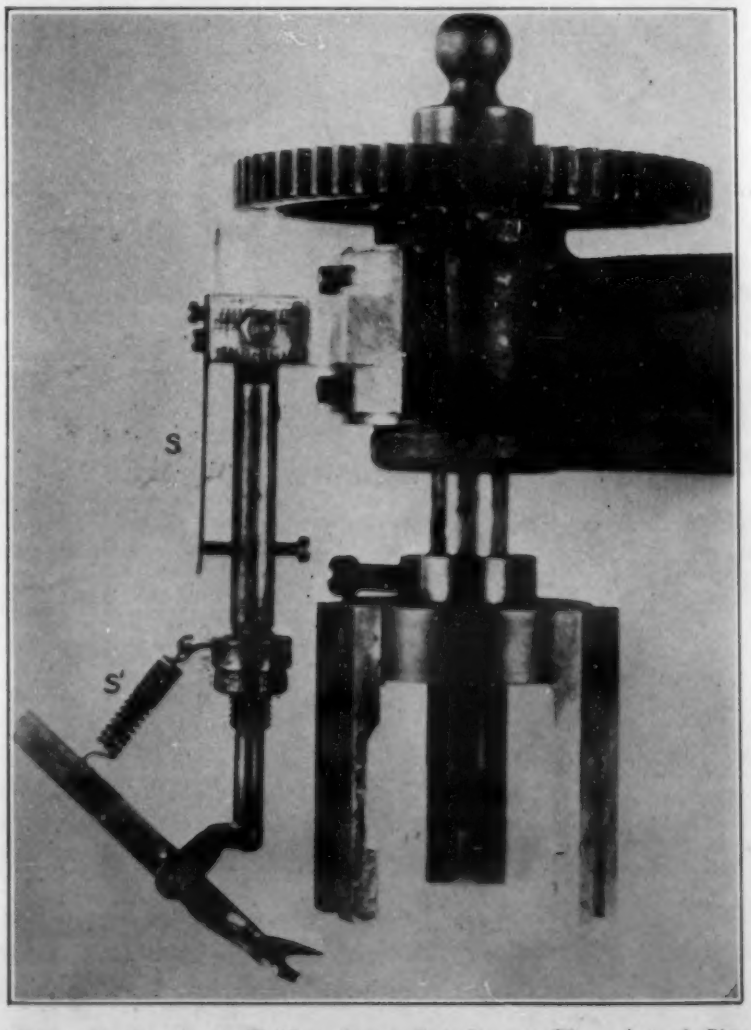

Figure 5—Specimen Holder, Somewhat Larger Than Actual Size
By means of the springs S and S' pressure is applied to the specimen holder in two directions, perpendicular to each other. The specimen, mounted in the ring, is held by means of the slots in the "fingers" which form lower part of device.

obtaining the necessary temperature and a steel die for holding the metal ring, may readily be made. The metal ring is fitted into the steel die, the specimen is inserted and the bakelite in powdered form is poured around it. The die may advantageously be preheated to the required temperature of about 150° C. Pressure is then applied and the molding is completed in about 10 minutes. Bakelite shrinks somewhat on cooling so that the molded specimen may become loose in the ring. This can be avoided by turning a few shallow grooves in the inner wall of the ring or else by drilling holes through the wall. There is no difficulty in knocking the bakelite out of the ring, which is then used over again. Figure 6 shows the press, steel die and small furnace used for the molding operation. A good many other substances have been suggested as mounting materials, such as blocking wax, ozokerite, dumold (pyroxylin base), dental cement, plastic wood, balata and paraffin. None of these seems to offer any special advantages. Some are soluble in alcohol, which is a great disadvantage in etching and cleaning the specimen.

Method of Polishing Used and Results Obtained

The stages in the automatic polishing procedure are exactly the same as those in hand-polishing followed at the Bureau. The specimens are first ground by hand with emery paper which is mounted on vertical disks directly attached to the armature shaft of a 500–1200 r. p. m. direct-current motor. Mechanical means for the grinding stages appear to be unnecessary since it is so rapidly done by hand. The papers used are emery paper 1/2 (American), Hubert (French) 1 G, 0 and 00. Recently, the quality of the finer papers available has not been of the best, and fairly deep grinding scratches have to be eliminated during the subsequent wet grinding with emery powder. This is a great disadvantage as it lengthens the time of polishing considerably and reduces the quality of the polish, for most of the pitting occurs during the wet grinding and polishing. Aloxite waterproof paper No. 400 is of excellent quality, although too coarse for the final grinding. It is unfortunate that a finer paper of this type such as No. 600 is not manufactured.

After the final grinding the specimen is mounted in sulphur, bakelite or white metal alloy. With the latter two materials, it is difficult to level the specimen with the mounting ring unless both are ground together after mounting. With sulphur, however, according to the procedure described, the specimen may be finally ground beforehand and then mounted perfectly level with the ring, no subsequent grinding on the emery papers being necessary; the precaution should be taken, however, of testing for planeness by rubbing on the final emery paper, before proceeding further.

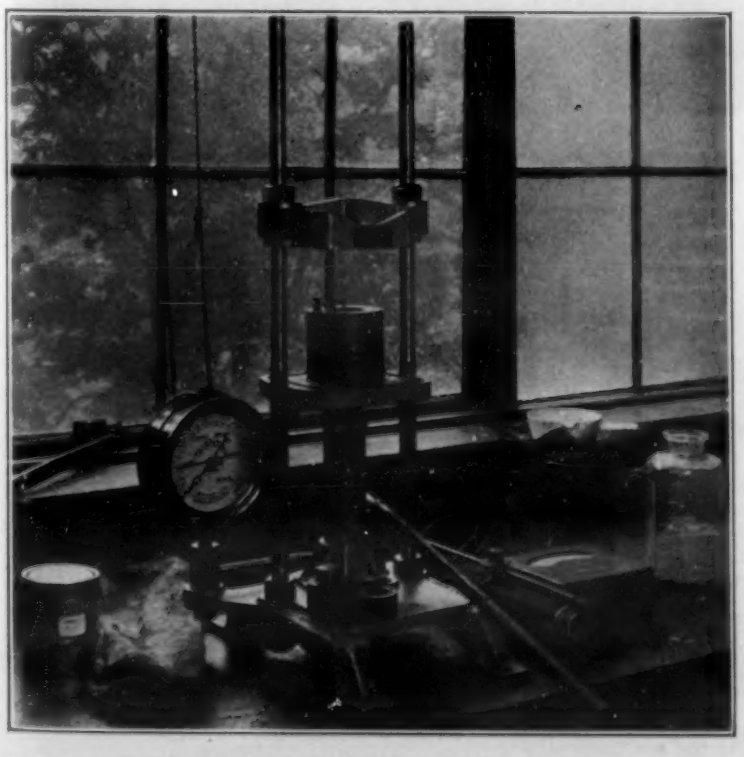

Figure 6—Press, Steel Die and Small Electric Furnace Used for Mounting Specimens in Bakelite

The mounted specimen is now polished automatically in the machine, first with 320 alundum suspended in water, then with either 500 or 600 alundum, and finally with Merck's reagent magnesia. For the alundum powders a strong cotton cloth, of about the same weave and weight as coarse linen, is used. Cotton cloth is superior to linen because of the knots and loose fibers usually present in the latter. The essential requisites of the cloth for wet grinding are a fairly coarse weave and absence of nap, otherwise pitting will occur. The emery powder and water should be used very sparingly. For the final polishing of the metal surface with magnesia the disk is covered with velvet. Care should be taken to brush the cloth-covered disks frequently with a stiff brush to clean them of débris and dirt. This applies especially to the magnesia disk since wet magnesia hardens on exposure to air. The magnesia is not previously mixed with water but is sprinkled dry on the moistened velvet cloth and then rubbed in with the fingers, water alone being supplied during the polishing. The support for the specimen holder may be easily wiped with a cloth or washed with water through a rubber tube. The spring is adjusted to press very lightly on the flange of the specimen holder, the amount of pressure being judged by lifting the holder. Auxiliary pressure is then applied through the pin which rests on the specimen, the pressure varying from about 3 to 6 ounces or more as desired.

For a high quality polish about 5 minutes' polishing is generally given with the coarser alundum, 10 minutes with the finer alundum, and finally 15 minutes with the magnesia. Generally the total time of polishing in the machine is about a half hour or somewhat longer, the time consumed depending largely on the quality of polish desired. For merely revealing the structure the pressure and speed may be increased and the polishing done more rapidly. Nevertheless, for any individual specimen, automatic polishing in the machine is not any faster than polishing by hand. The saving in time only becomes considerable when a good many specimens are to be polished. With three specimens polishing on one disk, nine specimens can be polished simultaneously on three polishing units, and twelve on four, which would be available if two of the double-disk machines described were used. Since the polishing is usually done in three stages three polishing units should be provided to obviate changing of disks and the difficulties attendant upon using more than one abrasive in a unit. Moreover, since the final polishing with magnesia takes the longest time, the best arrangement might be to have four disks; the final polishing could then be done on two of the disks, and the coarse and fine wet grinding on the other two. As a matter of fact the polishing machine has proved to be a great convenience, whenever a high grade polish is desired, even when the number of specimens to be polished is small and practically no time is saved by using the machine. In the laboratory it was found that men inexperienced at polishing quickly learned to get good results with the machine—very much sooner than they could have learned to polish by hand, which, of course, is a most valuable advantage.

A very high quality polish, fully the equal of that possible by hand, is obtained in the machine. The criterion of a good polish is not so much the absence of scratches, although that is, of course, important, as the freedom from pitting, especially in low carbon steels. In fact, tests of the quality of steel based on the number and type of inclusions present are worse than useless unless a good quality polish free from pitting is to be had. Figure 7 shows a number of micrographs of inclusions in steel specimens polished in the machine; the microsections appear to be quite free from pitting. Figure 8 shows micrographs of a cracked piece of rail steel and of a specimen of gray cast-iron. In examining cracks it is very desirable to get as little pitting as possible; gray cast-iron is

seldom well-polished because of the dragging out of graphite flakes. As may be seen in these micrographs, the cracks in the steel do not appear to have been widened or pitted during the polishing, and the graphite flakes in the cast-iron are sharply defined and intact. The softer metals may also be polished successfully in the machine. Figure 9 shows the results obtained on tin, wrought duralumin and cast aluminum.

Proposed Outline of Study of Polishing Methods

As was stated in the introduction, the primary purpose in undertaking this work was to study the effect of the variables in the polishing procedure with a view to working out a recommended practice and also perhaps to go into the theoretical aspects of the subject. Aside from developing the automatic machine, little progress has been made, but a brief outline of the proposed work may be given. The most obvious matters for study are the most suitable pressures and speeds for the various stages of polishing of the different metals. Here the use of an automatic machine, by which reproducible results should be obtainable, will be of value.

The subject of the best cloths has always been an uncertain matter. After a cloth has been chosen a constant source of supply should be made available. Various disks have been suggested as improvements over cloth such as paraffin, pitch, white metal alloy, cast-iron, aluminum, etc. Such disks have been tried and discarded by many investigators, but it is perhaps possible that with proper lubrication they may prove successful. The grinding and polishing powders have usually been suspended in water, although soap solutions and oil have been tried. Polishing powders are now marketed in which the abrasive is held in suspension in an oil or gum base liquid. Possibly such compounds may improve results and reduce the amount of abrasive consumed.

The question of grinding papers is an important one, especially the finer grades. If a satisfactory fine paper were available it would be possible to improve considerably the quality of polish and save time, and one of the steps in the wet grinding might even be eliminated. The main requirements of abrasive powders are their cutting quality and uniformity, and these might advantageously be studied with the microscope. A large number of grinding powders are available under different trade names; recently, due to the problem of polishing the hard tungsten carbide alloys, calcium boride and boron carbide have been added to the list. Titanium nitride is one of the hard materials to be tried out.

The number of polishing powders is also very great, among them being the oxides of iron, chromium, tin, zinc, manganese, aluminum and magnesium. From the standpoint of cleanliness the last two, which are white powders, appear to be the most convenient. Tin oxide is also a white powder. Glazebrook[4] states that putty powder (SnO_2) was at one time extensively used as a polishing powder but has been discarded for reasons of health. Magnesium oxide appears to be the most uniformly fine powder available. An objection to its use is its tendency to harden on exposure to air. The usual grade of levigated alumina contains traces of alkali, which are objectionable for polishing aluminum and its alloys, because the surface becomes tarnished. Alkali-free alumina of a fineness equal to magnesia would be preferable to the latter because of the tendency of magnesia to harden.

A microtome is available in this laboratory, and the question of the preliminary preparation of a plane surface of soft metals by means of this instrument will receive attention. An interesting proposal for preparing specimens with a cutting tool is that of turning with a diamond. This has been tried by the Bausch & Lomb Co. and may, perhaps, be considered further.

The question of the mechanism of the polishing action has long provided a topic of discussion to physicists, the principal issue being whether the action consists in removing the glass or metal from ridges or in flowing the material and filling in the grooves left by grinding. Apparently, measurements made on glass spheres during polishing[5] show an appreciable decrease

[4] Glazebrook, "Dictionary of Applied Physics," vol. **IV**, page 339.

[5] J. W. French, "Some Notes on Glass Polishing," *Trans. Optical Soc. Lond.*, **XVII**, 2, 24, Nov., 1916.

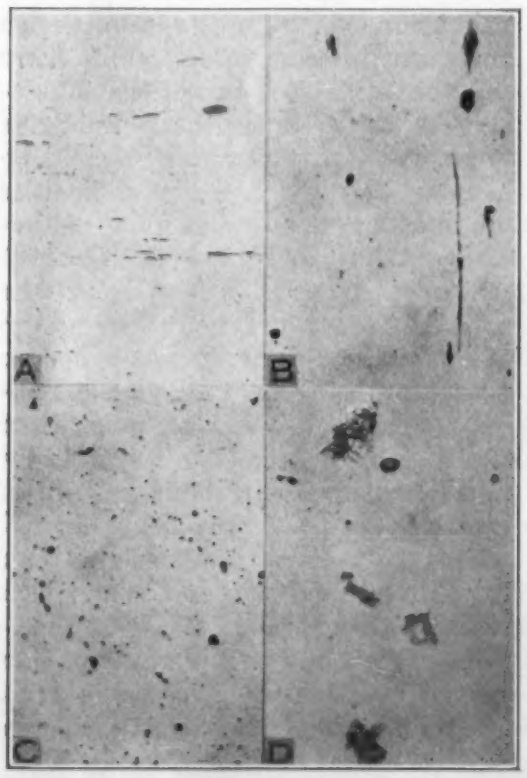

Figure 7—Representative Micrographs of Steel Specimens Polished in the Machine, Showing Various Types of Inclusions. Not Etched. These Microsections Appear to Be Practically Free from "Pitting" (1/2 reduction)

a. Sulphide inclusions in rail steel, × 100.

b. Alumina and sulphide inclusions in carburizing steel, × 500.

c. Large number of inclusions in experimental medium carbon steel ingot deoxidized with boron, × 100.

d. Same as *c* but at × 500; silicate, sulphide and iron-boron-carbide inclusions are shown.

Figure 8—Micrographs of Steel and Cast-Iron Specimens Polished in Automatic Machine (1/2 reduction)

a. Rail steel showing small cracks, × 500. Etched with 5 percent picric acid in alcohol.

b. Gray cast-iron showing graphite flakes and inclusions, × 500, not etched.

Practically no pitting or rounding off of edges was produced at the cracks by the mechanical polishing. The graphite flakes also remained intact.

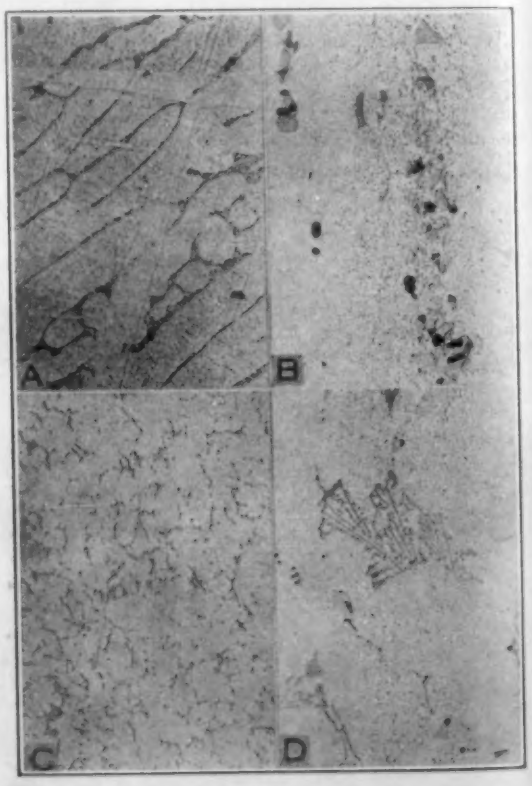

Figure 9—Micrographs of Several Specimens of Softer Metals Polished in the Machine (1/2 reduction)

a. Tin (0.25 Cu; 0.02 Pb; 0.02 Fe; Zn not detected), showing dendritic structure and large twins, × 500. Etched with 10 percent aqueous solution of potassium hydroxide.

b. Segregated spot in wrought duralumin, × 500, not etched.

c. Cast aluminum, × 100, not etched.

d. Same as *c*, × 500.

in diameter indicating that material is removed. There is also evidence that surface flow occurs, so that probably both removal and flowing take place during polishing. Rosenhain has observed that all of the usual polishing materials are oxides and he therefore supposes that the polishing action may be partly chemical.

Acknowledgment

Acknowledgment is gratefully made to Dr. H. W. Gillett, previously Chief of the Division of Metallurgy, who initiated this study and whose encouragement made possible the building of the automatic polishing machine.

The Twelfth Annual Meeting of the Gesellschaft für Metallkunde

September 7–9, 1929, Düsseldorf, Germany

The Twelfth Annual Meeting of the Gesellschaft für Metallkunde opened with a business meeting at 9:30 Saturday morning in the lecture-hall of the Verein deutscher Eisenhüttenleute. At the business meeting it was decided to create a Heyn memorial medal in memory of the first president of the society. The first medal was awarded to Prof. Tammann of Göttingen for his notable contributions to the advancement of the science of metals. It was also decided at this meeting to award three prizes for the best paper on the subject of "The Nature of the Metallic State." All papers must be submitted to a special committee of the Society, three years hence.

The guest lecture was delivered by Dr. W. Rosenhain (Teddington, England; President of the Institute of Metals) on "Physics and Metallurgy (Physik und Metallkunde)." A close relation of the two subjects is necessary due to the tremendous progress made in both fields during the last 10 years. Dr. Rosenhain opposed the viewpoint of some physicists that metallurgical research is no longer necessary, as atomic physics will soon permit the calculation of metal properties from theoretical data. The atom models did not prove satisfactory and were therefore replaced by mathematical equations. These also did not give entirely satisfactory results. Metallurgy will therefore remain an important science and its findings will always be necessary for the further advance of our knowledge of the metallic state. Rosenhain then discussed some recent developments in the science of metals. He described, for example, how the color of different alloys is related to the distortion of the space lattice of solid solutions and considered the question of differentiation between solid solutions and intermetallic compounds. In conclusion, Rosenhain emphasized the importance of promoting international cooperation, as the scientists of the different countries very often are not familiar with the work done in other countries on the same or related subjects, so that much time and effort is wasted.

The next lecture was on "Characteristics, Nature and Possibilities of Age Hardening (Kennzeichen, Wesen und Zukunftsmöglichkeiten des Vergütung von Legierungen)" by Dr. W. Guertler (Berlin). Age hardening of pure metals was not possible heretofore because allotropic changes of pure metals procede either quantitatively or do not take place at all. The ordinary dispersion hardening is discussed in its different steps. The precipitation process is comparatively simple if a migration of atoms is not necessary for the formation of the new phase. The conditions are much more complicated when two types of atoms form the new compound by migration (for example Mg_2Si and Al). If the aging takes place at room temperature, where a migration of atoms seems to be impossible, we must conclude that the molecules of Mg_2Si were closely associated before the quenching. A complete understanding of the aging phenomena will not be possible before the physical chemistry of the crystalline state has been systematically developed.

"Age Hardening Aluminum Alloys (Vergütbare Aluminiumlegierungen)," was the title of a paper by Dr. W. Fraenkel (Frankfurt a. M.) who briefly reviewed the different types of aluminum alloys and discussed Merica's dispersion hardening theory.

Dr. G. Masing (Berlin) spoke on "Age Hardening Copper Alloys (Vergütbare Kupferlegierungen)," which were found after the process of dispersion hardening had been studied sufficiently in the case of the aluminum alloys. Age hardening can be of practical importance not only if extreme properties can be attained but also in the case of the combination of certain properties. Age hardening alloys of Cu, Fe, Ni, Co and Pb base were considered by Masing and the practically important alloys (Heusler, Corson and Beryllium alloys) are described. The investigations of these non-aluminum base age hardening alloys gave valuable information on the nature of age hardening.

Dr. L. Nowack (Pforzheim) read a paper on "Age Hardening Precious Metal Alloys (Vergütbare Edelmetallegierungen)." Dispersion hardening is known in alloys of Ag-Cu, Ag-Cu-Cd, Au-Ni-Si, Au-Ni-Al, Au-Pd-Zn. Characteristic age hardening could also be observed by the speaker in alloys of 75% Au and 25% Pt and in Fe-Au alloys with 15–20% Fe. Au-Ni alloys, which have considerable practical importance, harden as a result of the decomposition of a solid solution of 10–90% Ni. The alloys suggested by Corson consist of a precious metal and three or more other metals. Here the dispersion hardening can be explained by the decreasing solubility at lower temperatures of Ni-Si or Ni-Al in Au, Au-Ag and similar solid solutions. The author found a new Au-Cu age hardening alloy with 50 atomic percent Au, in which the solid solution decomposes forming an intermetallic compound AuCu or $AuCu_3$. This type of age hardening alloy consists of a single phase before and after transformation, while two phases coexist during transformation. The hardening of alloys of the composition AuCu is considerable, while no increase in hardening can be observed in the case of $AuCu_3$. The speaker suggested that this is due to the fact that in the case of AuCu, the cubic face centered space lattice is transformed into a face centered tetragonal lattice. In the $AuCu_3$ alloy, however, the solid solution and the intermetallic compound are both of the same atomic arrangement with only varying lattice constant. Similar conditions were observed in alloys of Cu with Pd and with Pt, which are of the greatest theoretical and practical importance.

The second day of the convention was opened with a paper "Age Hardening of Copper-Zinc Alloys (Über den Vergütungsvorgang in Kupfer-Zinklegierungen)," by Dr. M. Hansen (Berlin). The decomposition of the supersaturated β solid solution was determined at various aging temperatures by measuring the change in electric resistance. At sufficiently high aging temperatures (350°–400° C.) the resistance increases slowly to a constant value. At 300° and 275°, however, a rapid increase to a maximum occurs with a subsequent drop to a constant value. The curves for 250° and lower show that the resistance increases in two marked steps. The different steps in age hardening were explained by the speaker. The influence of the amount of supersaturation, the quenching rate and the quenching temperature on the resistance during aging were also investigated.

Dr. M. Haas (Aachen) discussed "A Contribution to the Hardening Problem of Silver-Copper Alloys (Beitrag zum Härtungs-problem von Silber-Kupferlegierungen)." The curve

of solid solubility on the silver side was investigated and the agreement with a previous paper of the author and the results of Hansen proved very satisfactory. The curves were determined by measurements of the electric conductivity and by dilatometry both with continuous rising and falling temperature. The continuous curves clearly showed the precipitation of the hardening phase (Cu-rich solid solution), its agglomeration and its resolution.

"A Contribution to the Hardening Problem of Alloys of Light Metals with Beryllium (Beitrag zum Härtungs-problem von Beryllium-Leichtmetallegierungen)" was the title of a paper by Dr. Denzo Uno (Aachen). The range of solid solubility on the aluminum side of the aluminum–beryllium diagram was investigated with the purest available alloys. Microscopic, dilatometric and electric conductivity analysis methods showed a somewhat higher solid solubility at higher temperatures, compared with the results of Oesterheld, Kroll, Archer and Fink. Aging experiments of aluminum-beryllium alloys and duralumin containing beryllium were discussed.

Dr. G. Wassermann (Berlin) spoke on "Dispersion Hardening of Magnesium-Zinc-Aluminum Alloys (Über die Vergütung der Magnesium-Zink-Aluminiumlegierungen)." X-ray investigations of the space lattice constant of aluminum in solid solution with other metals show that additions of zinc contract the lattice, while magnesium widens it. If magnesium and zinc are both added in the proportion of the compound $MgZn_2$ the space lattice constant is also widened somewhat. With these facts as a basis and taking into consideration the atom volumes and atom diameters of the different constituents the author considers the question, whether the $MgZn_2$ is in molecular solution in the aluminum base or whether the Mg and Zn atoms are in complete solid solution. The results indicate that the $MgZn_2$ is contained as such in the aluminum and not as a solid solution. Wire of commercial "Constructal" (aluminum alloy of Zn and Mg) was used in aging experiments. Variations in hardness and in space lattice constant were measured simultaneously. The variations observed were comparatively small due to the magnesium and zinc opposing each other in their action on the lattice constant of aluminum. The lattice constant decreases by about 0.0015 A. U. during the first 24 hours' aging at room temperature and the first 30 minutes' aging at 80° C. Further changes, which might occur, could not be detected as the limits of experimental error were attained.

"Kinetic Measurement of a Transformation Reaction in the Solid State (Kinetische Messung einer Umwandlungsreaktion in festem Zustand)" was the title of a paper by Dr. W. Fraenkel and Dr. Wachsmuth (Frankfurt a. M.). A reaction taking place at about 270° C. at about 20% Al in the Al–Zn system was investigated by a dilatometric method. Contrary to the prevailing opinion, the results indicate that the reaction shows a certain acceleration at the beginning. The relation of the reaction rate and the quenching temperature was investigated and a mathematical formula derived.

Dr. O. Dahl (Berlin) read a paper entitled "Kinetics of the Eutectoid Decomposition of γ-Bronzes (Zur Kinetik des eutektoiden Zerfalles der γ-Bronzen)." The eutectoid decomposition and the age hardening of bronzes in the $(\alpha + \gamma)$ and $(\gamma + \delta)$ ranges, quenched above the temperature of eutectoid decomposition, was studied by means of resistivity-time curves at different temperatures (150–400° C.). At aging temperatures of 220 and 300° the electrical resistivity increases at first, then decreases somewhat and finally increases again. At an aging temperature of 150° C., only the first increase and decrease are observed, while at a temperature of 400° C. only the decrease and the second increase can be observed. The age hardening observed by Matsuda takes place during the first increase and decrease of the electrical resistivity. This can be seen from the hardness-time curves. The eutectoid decomposition of the β-phase in Al-Cu alloys takes place in a similar way as shown in an 11% alloy. The first increase of the electric resistivity, however, could not be observed in this case.

"The Investigation of the Constitution of Binary Alloys by Measurements of the Electric Conductivity and Thermal Expansion (Die Untersuchung der Konstitution binärer Legierungen durch Messung der elektrischen Leitfähikeit und thermischen Ausdehnung)" was the title of the paper read by Dr. G. Grube (Stuttgart). Transformations in the solid state often proceed very slowly and are not characterized by sufficiently large thermal effects, so that they cannot be detected by thermal analysis. Changes of electrical resistivity and thermal expansion were used for the detection of such transformations. The critical points determined in this way can be conveniently used for the construction of the constitutional diagram. The methods described were used for the investigation of the equilibrium diagrams of Au-Cu, Mg-Zn, Mg-Al and Mg-Cd. In all cases interesting results were obtained. New transformations which were previously unknown were found and a number of new intermetallic compounds were detected. In the Au-Cu alloys, for example, the curves showed maxima at 50.5, 25.5 and 20.8%, which indicates three compounds. The author points out that the maxima of the curves do not correspond exactly with the compounds Au_3Cu, AuCu and $AuCu_3$ but are displaced somewhat.

Following the last paper of the morning session, a discussion as to the nature of solid solutions and intermetallic compounds took place. Tammann, Guertler, Rosenhain, Sachs, Masing, Wassermann and others took part in the discussion.

The afternoon session was opened by Dr. A. Schulze (Berlin) with a paper "On Transformation Products of Metals (Über die Umwandlungsprodukte von Metallen)." Experiments conducted at the Physikalisch-Technische Reichsanstalt indicated that spectroscopically pure zinc (New Jersey Zinc Company) has a smooth electrical resistivity curve and that only lower purity grades of zinc show certain discrepancies, which causes the belief of allotropic changes. In bismuth (with total impurities of .01%) dilatometric, electrical resistivity and microscopic methods gave no indication of a transformation at 75° C. as reported by Cohen and Moerveld. In thallium the transformation takes place at 227° C. Different physical properties in this range are reported. Cobalt of the highest purity and lower grades were investigated at the transformation point (470° C.). Measurements of electrical properties at the Curie point (1125°) show similar results as also nickel and iron.

Dr. R. Kühnel (Berlin) spoke on "Peculiar Grain Growth in Steel and Copper and Its Causes (Aussergewöhnliches Kristallwachstum an Eisen und Kupfer und seine Ursachen)."

In the next paper "The Influence of Recrystallization on the Technical Behavior of Lead (Der Einfluss der Rekristallisation auf das technische Verhalten von Blei)," F. Brenthel (Halsbrücke) discussed the recyrstallization tendencies of different grades of lead, the influence of copper and some corrosion problems. He claimed superior corrosion stability for the Pattinson lead due to the presence of copper and its extremely uniform distribution.

Dr. M. V. Schwarz spoke on "Comparative Investigations on Light Metal Piston Alloys (Vergleichende Versuche Über Leicht-Metall-Kolbenlegierungen). He gave a descriptive review of the development and present-day status of aluminum alloys for die-cast pistons. He considered the alloys of aluminum with 12 to 18% Cu and with 20% Si. The latest development is represented by aluminum alloys, which contain in addition to copper, certain amounts of metals of the iron group. The hardness of these alloys closely approaches that of ordinary cast iron. The physical properties at elevated temperatures are good and the heat expansion better than in the other die-casting alloys.

Dr. H. Bablik (Vienna) read a paper on "Bending Properties of Zinc Coatings (Biegefähigkeit von Zinküberzügen)."

Experiments conducted by the author showed that good non-corrosive zinc coats must be non-porous. In agreement with the findings of the American Society for Testing Materials, the author's results indicated that the thickness of the coat has no influence on the bending properties. Cracking of the coating is due to intermetallic iron-zinc compounds located in layers between the steel base and the zinc. It should therefore be possible to produce very elastic coats, provided it were possible to entirely avoid the formation of these layers. The reduction of these layers to a minimum is possible by a close control of all factors during the galvanizing operation: time, temperature, etc. The author also suggests the use of electrolytic zinc due to its great purity.

The final paper "Recent Observations on the Rolling of Electrolytic Copper (Neuere Beobachtungen bei der Knetbearbeitung von Elektrolytkupfer nach gemeinsamen Versuchen von K. Bernhoeft und W. Wunder)" was read by W. Wunder. Extensive experiments conducted over a number of years clearly showed that the following factors have considerable influence on the quality of the wire: 1. Purity of the copper; 2. Control of the interior of the ingot; 3. Definite Tapping Temperature and 4. Definite preheating temperature of the mold. The authors expressed the belief that in spite of the greatest care no wire mill succeeds in producing more than 95% of satisfactory wire bars. After rolling and drawing defects are often found in wire, which becomes brittle in places, also sheets, which do not give a satisfactory polished surface. Experiments showed these defects are due to small cracks formed during rolling and welded together in the following passes or drawings. The material is weakened in these places. The authors recommend that the greatest attention be paid to the rolling where the cracks can be avoided.

Monday morning the opportunity was offered for visiting any of the following: Kaiser-Wilhelm-Institut für Eisenforschung, Giesserei-Fachausstellung, J. G. Schwietzke Metallwerke, Walzmaschinenfabrik August Schmitz, Demag A. G. and Duisburger Kupferhütte.

In the evening, the members of the Institute of Metals and the Deutsche Gesellschaft für Metallkunde attended a banquet in the Rheingoldsaal of the Hofgarten-Rheinterrassen. This dinner concluded the convention of the German Society and at the same time marked the beginning of the Annual Autumn Meeting of the Institute of Metals, assembled in Germany for the first time as the guests of the Deutsche Gesellschaft für Metallkunde.

Prof. Guertler welcomed the English guests. Dr. Masing addressed the members of the society and their friends, while Dr. Rosenhain spoke as the president of the Institute of Metals. —KARL KUETTNER.

Editor's Note: The meeting of the Institute of Metals will be reported in an early issue.

Malleable Iron—Short Cycle Anneal

I. R. Valentine*

Some time ago we started an investigation on the annealing of hard iron (malleable composition) with a view of learning something of the mechanism of the carbon precipitation and the possible shortening of the process. The annealing of hard iron seems to resolve itself into two distinct parts: First, the passing of free cementite (Fe_3C) into solid solution. Second, the precipitation of carbon from solid solution as graphite (temper carbon).

Solid Solution

The absorption of Fe_3C into solid solution is a question of temperature and time.

At 1100° C. (2012° F.) solution was effected in about 15 minutes.
At 1050° C. (1922° F.) solution was effected in about 2 hours.
At 1000° C. (1832° F.) solution was effected in about 3 hours.
At 950° C. (1742° F.) solution was effected in about 10 hours.
At 900° C. (1652° F.) solution was effected in about 30 hours.

A temperature of 1100° C. (2012° F.) is too close to the softening point of the iron to be of much commercial use as the castings would be badly distorted while temperatures below 900° C. (1652° F.) are too low for a quick absorption of cementite, with the final anneal running out into present practice so far as time is concerned.

Carbon Precipitation

Solid solution being effected, the precipitation of carbon is now involved and this also seems to be question of time and temperature.

At a temperature of 900° C. (1652° F.) practically no precipitation occurred at the end of 100 hours. As the temperatures are lowered, precipitation proceeds at a faster rate until a maximum is reached which is between 750° C. (1382° F.) and 700° C. (1292° F.) and then precipitation is retarded until a minimum rate (no precipitation) is reached which is at 650° C. (1202° F.).

Process

Minimum time for solid solution and maximum rate of carbon precipitation being established, we built 130 K. W. Electric Furnaces—capacity 2000 lb. castings which was put into operation and continued until recently when our present installation was put into operation.

* General Electric Company, Schenectady, N. Y.

Electric Furnaces

The new installation consists of three (3) 325 K. W. Electric Furnaces—11,000 Volt primary, 236 Volt secondary; the heating elements are made of nickel-chromium and are connected three phase or single phase so that a power range of 52 K. W., 170 K. W. or 325 K. W. is available. Capacity 100 tons of castings per week.

Operation

The hard castings (cleaned or uncleaned) of commercial composition, are packed on the car bottoms, with or without iron plates or in boxes, depending on the nature of the load.

Short Cycle Anneal Car, Laboratory, Building 18, Erie Works

Stacking directly on the car is preferred. The load is heated to a sufficiently high temperature (High Temperature Furnace) to effect solid solution, this being accomplished, the car hearth (castings) is transferred to the Low Temperature Furnace where the cooling and drawing operation is effected. The castings are cooled to 740° C. (1364° F.) when the draw is

350-K. W. Electric Annealing Furnaces, Short-Cycle Process (24 Hours) Malleable Iron Foundry, Building 22, Erie Works

started. This temperature is maintained for 4 hours when a 10° C. (18° F.) drop in temperature is made to 730° C. (1346° F.) and this temperature is maintained for 4 hours when a second 10° C. (18° F.) drop in temperature is made to 720° C. (1328° F.) and this temperature maintained for 4 hours after which the castings are transferred to a cooling furnace or into the air. Tests are taken at the end of the 730° C. (1346° F.) draw to determine the condition of the anneal. The average time for 6-ton anneal is between 28–30 hours.

Physical Properties

	A.S.T.M.	Regular anneal	Short cycle, anneal
Tensile Strength	50,000	53,000	56,000
Yield Point	30,000	34,800	34,300
Elongation 2"	10%	15%	15%

The malleable iron (short cycle) machines better than our regular product and shows no signs of framing or reversion. There is very little skin and the castings clean somewhat easier than the regular product. It can be quenched directly from the 720° C. (1328° F.) draw with increased strength without brittleness. It may be galvanized without embrittlement and needs no previous treatment (Flecto Process) or subsequent treatment (General Electric Co.'s Aging Process). Warpage of castings is less than in the regular anneal.

With this process, it is possible to produce Malleable Iron in

Switchboard for 350-K. W. Electric Annealing Furnace, Short-Cycle Process (24 Hours) Malleable Iron Foundry, Building 22, Erie Works

30 hours or less and eliminate the following from our usual anneal.

1. Boxes and packing material.
2. Hard cleaning (if desirable).
3. Less labor.
4. Less inventory.
5. Short delivery.
6. Cleaner operation.
7. Not over two days behind the melting furnaces.
8. Less space.
9. Composition (hard iron) control.
10. Lower cost.

The process is one requiring delicate thermal control and I do not believe such control can be obtained in any type of combustion furnace.

The American Society for Testing Materials' Committee A-2 on Wrought Iron, of which Mr. H. W. Faus, Engineer of Tests of the New York Central Lines, is chairman, and Mr. G. H. Woodroffe, Manager of the Boiler Tube Department of the Reading Iron Co., is secretary, is engaged on the study of what constitutes quality in wrought iron. The information gathered by the committee on this subject should be of importance to the entire wrought-iron industry. The committee has also completed physical and chemical tests to determine the effect of phosphorus on the physical properties of staybolt iron. The results of these tests will appear in the annual report of the committee for 1930.

The committee is engaged in the preparation of a definition for wrought iron. With the adoption of this definition it is expected that the process clauses of the various A. S. T. M. specifications covering wrought-iron products will be revised to include wrought iron made by any process so long as the other requirements of the specifications are complied with.

A revision is under consideration of the Specifications for Staybolt, Engine-bolt and Extra-refined Wrought-iron Bars and of the Specifications for Hollow Rolled Staybolt Iron to consist of a change of the definition of "box pile," and an increase in the requirements for reduction in area in the latter specifications from 42 to 48 percent.

Several errors appeared in the translation "A Contribution to the Knowledge on the System Nickel–Iron," which appeared in the July issue.

The city of Eindhoven is in Holland and not in Germany. The name of the second author should read Zwikker instead of Zwicker. In the first paragraph it reads "The material in the desired proportion was heated in a fire clay crucible of an electric furnace about 500° C. above the melting temperature." This should read 50° C.

The name Schultze in the footnote should read Schulze, and the name of D. J. Coumou reads D. J. Coumon.

The investigation described in this article was carried out in the physical laboratory of N. V. Philips' Gloeilampenfabrieken.

The annual convention of the International Acetylene Association will be held at the Congress Hotel, Chicago, November 13, 14 and 15. This annual meeting is an outstanding event in the oxy-acetylene field each year and the programs from year to year have furnished some exceedingly valuable and significant contributions to the literature of welding. It will be remembered that at last year's convention there was presented a report of the Oxy-Acetylene Committee of such length that it was necessary to print it for distribution. This report has been very much in demand because of the comprehensive picture it presents of the uses of oxy-acetylene welding in all of the major industries of the country. Since that time the same committee has been working constantly to amplify some portions of last year's report and to assemble new material on subjects which were not covered last year. In addition to this, there have been a number of interesting developments in the field of oxy-acetylene welding and cutting, all of which will be covered in interesting detail by technical papers which are in course of preparation and will be presented at the meeting.

The Program Committee has made definite arrangements fo a number of papers of unusual interest and it is expected that some detailed information on this subject will be available very soon. Those interested in the promotion of oxy-acetylene welding and cutting can be sure of finding both pleasure and profit in attending the coming meeting.

In the translation "The Corrosion of Brass" appearing in the October issue of METALS & ALLOYS on pages 183–189, at the end of the article on page 189 the suggested copper contents of 63 brass is given as 63 ±0.02%, wheras it should read 63 ±0.20%.

Critical Abstracts

Dr. Gillett, the editorial staff and specially selected contributors will prepare abstracts of a critical nature on articles of special importance. The current literature will be covered in the Abstracts of Current Metallurgical Literature.

Testing the Corrosion-Resistance of Alclad*

Erick Rackwitz and Erick K. O. Schmidt

In this contribution from the German Aeronautical Laboratory (DVL), the authors have presented the results of a comprehensive series of corrosion tests on aluminum-coated duralumin ("Alclad") plain duralumin and aluminum sheet. The various tests were as follows:

(*a*) The three sheet materials, of various strengths (thickness), corroded by means of a 3 percent sodium chloride solution containing 0.1 percent H_2O_2 (accelerated corrosion test).

(*b*) The same materials corroded by a spray test of 20 percent sodium chloride solution.

(*c*) Riveted Alclad sheet corroded as in *a*.

(*d*) Alclad sheet having different thicknesses of the aluminum surface layer, corroded as in *a*.

(*e*) Corrosion of Alclad with the surface layer damaged and also cold worked.

(*f*) Corrosion of duralumin sheet in combination with pure aluminum.

The testing procedure used by DVL has been described in detail in *Korrosion und Metallschutz*, 5, 6 (January, 1929).

The Alclad sheet (Aluminum Company of America) had the following thickness, 0.8, 1.6, 2.6 and 3.2 mm.; the duralumin sheet (Dürener Metallwerke), 1.0, 1.5, 2.0 and 4.0 mm.; and the aluminum sheet (Handels-Aluminium, 98.99% Al), 0.8, 1.5, 2.5 and 3.0 mm. All specimens were longitudinal, that is, parallel to the direction of rolling.

RESULTS

In summarizing the results the same designations as are given above are used.

A. Accelerated Corrosion Test.—The tests were carried out by immersion for 5 days at 20° C. ±1° in the sodium chloride solution which was stirred (the stirrer working at 135 r. p. m.) and the hydrogen peroxide content was renewed, according to the results of daily titrations. Eight specimens were tested at once in the 9-liter volume used. Observations were made on the change in surface characteristics, loss of weight, loss of strength and loss of ductility.

The surface appearance of the Alclad sheet after corrosion varied greatly according to the thickness of the sheet. The thinner sheets (0.8 and 1.6 mm.) were very uniformly etched over the surface and no pronounced attack along the edges occurred. In the thicker sheet (2.6 and 3.2 mm.) the surface was irregularly attacked and the edge corrosion was very marked. The exposed duralumin (basis material) was colored brown and showed numerous brown flecks and streaks (corrosion centers) which were practically entirely lacking in the thinner sheets. Intercrystalline corrosion was not observed in any case, however.

The weight losses shown by the different materials are summarized in Figure 1.

The changes in the tensile properties are summarized in Table 1.

* *Korrosion und Metallschutz*, June, 1929, pages 130–141.

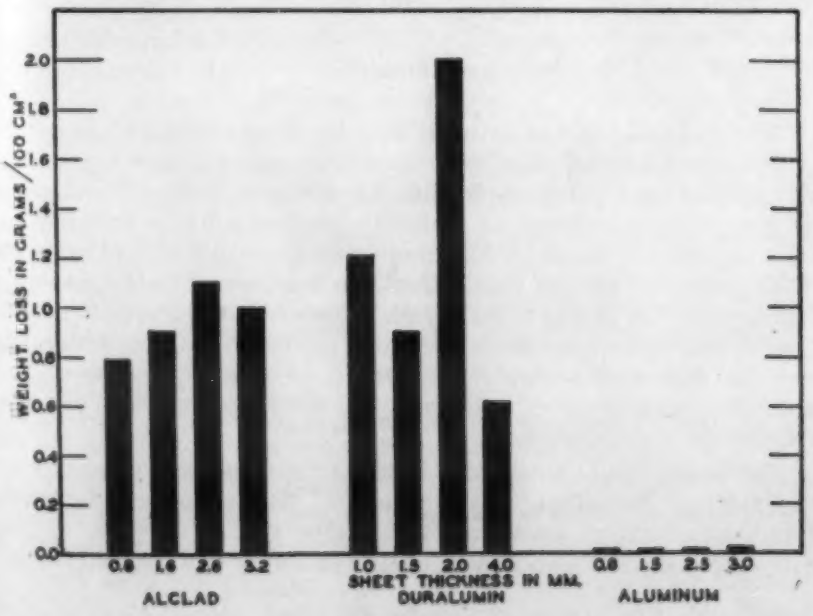

Figure 1

Table 1—Average Changes in Tensile Properties of Alclad, Duralumin and Aluminum Sheet after 5 Days' Corrosion in 3% Sodium-Chloride Solution Containing 0.1% H_2O_2

Material (longitudinal specimens)	Sheet thickness, Mm.	Tensile strength Initial Kg./Mm.²	Initial Lb./In.²	After corrosion Kg./Mm.²	After corrosion Lb./In.²	Loss %	Elongation Initial %	Elongation After corrosion %	Loss %
Alclad	0.8	37.7	53,600	37.2	52,900	(1.4)[a]	18.3	16.6	9.2
	1.6	39.2	55,750	38.6	54,900	(1.5)	20.0	20.4	0.+
	2.6	38.6	54,900	38.1	54,200	1.4	16.7	18.5	0.+
	3.2	38.7	55,050	38.5	54,750	0.5	19.7	20.6	0.+
Duralumin	1.0	44.2	62,850	33.8	48,050	23.6	20.5	7.3	68.4
	1.5	43.5	61,850	35.9	51,050	17.4	18.3	8.7	52.4
	2.0	46.5	66,150	34.2	48,650	26.5	16.1	3.4	78.8
	4.0	40.4	57,450	39.2	55,750	2.0	20.5	16.3	20.5
Aluminum	0.8	12.7	18,050	12.2	17,350	(4.0)	10.3	9.4	(8.8)
	1.5	16.2	23,050	16.1	22,900	(0.6)	6.7	6.4	(4.5)
	2.5	16.5	23,450	16.0	22,750	(3.0)	6.7	7.7	0.+
	3.0	17.2	24,450	17.1	24,300	(0.0)	7.0	7.9	0.+

Table 2—Average Weight-Loss of Alclad, Duralumin and Aluminum Sheet in the Salt-Spray Test

Material	Thickness, Mm.	Surface area, Cm.²	Average Loss of Weight After 22 days G./100 Cm.²	After 66 days G./100 Cm.²
Alclad	0.8	45.1	0.0120	0.0497
	1.6	61.6	0.0070	0.0704
	2.6	76.4	0.0134	0.0495
	3.2	78.8	0.0065	0.0677
Duralumin	1.0	48.5	0.0238	0.1517
	1.5	65.2	0.0416	0.2360
	2.0	76.5	0.0791	0.2558
	4.0	85.6	0.0474	0.2538
Aluminum	0.8	50.5	0.0119	0.0665
	1.5	66.7	0.0057	0.0710
	2.5	78.7	0.0064	0.0524
	3.0	80.3	0.0027	0.0747

Table 3—Change in Tensile Properties of Alclad, Duralumin and Aluminum Sheet Produced by Corrosion for 66 Days in the "Salt-Spray" Test

Material	Thickness, Mm.	Tensile strength Initial Kg./Mm.²	After corrosion Kg./Mm.²	Loss %	Elongation Initial %	After corrosion %	Loss, %
Alclad	0.8	37.7	37.9	(0.+)[a]	18.3	15.6	14.7
	1.6	39.2	38.9	(0.7)	20.0	20.8	0.+
	2.6	38.6	38.1	(1.2)	16.7	18.1	0.+
	3.2	38.7	38.8	0.+	19.7	21.1	0.+
Duralumin	1.0	44.2	33.4	24.5	20.5	3.2	84.4
	1.5	43.5	39.5	9.2	18.3	8.2	55.2
	2.0	46.5	40.5	12.8	16.1	5.1	68.4
	4.0	40.4	40.4	0.+	20.5	17.5	14.6
Aluminum	0.8	12.7	12.4	(2.3)	10.3	10.8	0.+
	1.5	16.2	16.3	(0.+)	6.7	6.1	(9.)
	2.5	16.5	15.9	(3.7)	6.7	7.5	0.+
	3.0	17.2	16.8	(2.3)	7.0	5.4	(22.8)

[a] The losses indicated in ( ) may be somewhat misleading since the individual values of the initial properties were in some cases greater than the average, after corrosion.

B. Spray Test.—A 20 percent sodium chloride solution was used, at room temperature, and the tests were continued for 22

and 66 days. Evidence of corrosion after 5 days' exposure to the spray was observed. The edges of the Alclad sheets showed a slight copper-red deposit, the duralumin sheets showed a much more severe attack over the surface as well as along the edges. At the close of the test, however, no very special significance could be attached to the visual appearance of the various specimens. No evidence of intercrystalline attack of any of the materials was observed. The relative weight-losses and changes in tensile properties at close of 22 days and 66 days in the "salt spray" are given in Tables 2 and 3.

C. Riveted Alclad Sheets.—Corrosion tests by immersion for 5 days in 3 percent sodium chloride solution containing 0.1 percent hydrogen peroxide (conditions as in A) were made on 2.6 mm. Alclad sheets riveted by means of duralumin rivets. The test was entirely qualitative, the surface appearance being depended upon as an index of the corrosive attack. The edges of the sheet showed some attack as indicated by the slight "copper" precipitation; the attack of the rivets was very slight; in the immediate neighborhood of rivets the aluminum surface of the Alclad was strongly attacked.

D. Influence on the Corrosion Resistance of Alclad Sheet of the Uncovered Areas (Edges) to the Aluminum Covered Surface.—To illustrate complete shielding of the cut edges, corrosion tests were carried out on the 0.8 and 1.6 mm. sheets pressed tightly against open glass cylinders, so as to form the bottom, the cylinders being filled with the 3 percent sodium chloride solution containing 0.1 percent hydrogen peroxide. An area of 80 cm.^{2} was used. A piece of 3.2-mm. sheet, with the edge partially shielded so that the ratio between exposed duralumin to the aluminum surface was 1:56, was suspended in one of the cylinders containing the sodium chloride solution and a piece of 3.2-mm. Alclad sheet with the edges fully exposed was suspended in the other. After 21 days, the aluminum surface of the specimens in which the edge-effect was entirely eliminated was extremely slight, the initial polish still remaining in one case. The specimen with partially shielded edges, after 21 days, showed a marked corrosive attack on the exposed edge ("copper precipitation") but the aluminum surface was only moderately etched. The specimen with fully exposed edges after 14 days showed marked edge attack and the aluminum surface was strongly etched and roughened. The tests were very limited; the conclusion was expressed, however, that corrosion resistance of Alclad sheet is increased by shielding the cut edges.

E. Effect of Imperfections in the Aluminum Coating.—To determine the effect upon the corrosion resistance of Alclad sheet of imperfect coatings, the aluminum layer on the 0.25 mm. sheet was deeply scratched with a chisel so as to expose the duralumin or basis metal. The scratched sheet was bent through 90°, the injured side being the convex one, and along the bend the sheet was filed. A second sample, 2.5-mm. sheet, was bent over a mandrel of different thicknesses, and a third sample was cold-worked by hammering it. The results of the corrosion tests in the sodium chloride solution (as in A) showed that neither in the scratched or filed spots in which the underlying duralumin was exposed nor in the bent or hammered spots was the sheet severely corroded. (The conclusion expressed in D is consistent with this observation.)

F. Corrosion of Duralumin in Contact with Pure Aluminum.—Tests were carried out to supplement the previous observations made on the edge-corrosion effect on the thicker sheets as well as the accelerated attack of the aluminum surface observed adjacent to the rivets in the riveted sheets. Pieces of aluminum sheet (99.6% pure) of different sizes were riveted to duralumin—the size of the latter (20 × 100 mm.) being constant throughout. The ratio of the duralumin surface to the aluminum varied as follows: 1:1, 1:1/4, 1:1/2, 1:2 and 1:2.75. In addition, an unriveted sample of each was used. The results of the corrosion tests (carried out as in A) showed that the duralumin, when not in contact with aluminum, was slightly corroded. When riveted to aluminum the attack of the duralumin was still less; the aluminum, however, was more strongly attacked than when used alone. No marked difference in the degree of corrosive attack corresponding to the difference in the relative area of the aluminum and duralumin specimen was observed. In a comparison set, however, in which the aluminum was replaced by Alclad sheet, the protection afforded the duralumin (presumably "electrolytic" protection) was noticeably less. The relationship of the actual electrolytic potentials of aluminum and duralumin was not studied further.

In summarizing the various test results, the general statement is made that although the Alclad sheet showed evidence of surface attack and some loss in weight when severely corroded by the accelerated corrosion test (immersion in a sodium chloride solution containing hydrogen peroxide) the strength properties were only very slightly affected by corrosion. The corresponding changes in the strength properties of duralumin sheet, however, under the same conditions were very pronounced. These findings are in excellent agreement with the results of similar extensive tests which have been done in this country on the same subject, particularly by the Bureau of Standards in cooperation with the National Advisory Committee for Aeronautics (*N. A. C. A. Tech. Notes* 282–285, incl., 304 and 305).

The coating of duralumin with aluminum, as in the Alclad process, is concluded by the authors to be the most notable advance in increasing the corrosion resistance of the high strength wrought aluminum alloys which has as yet been made.—H. S. Rawdon.

Possibility of Enlargement by X-rays

(*Continued from page 225*)

Figure 4 illustrates the effect of interposing a material of varying opacity to X-rays in the path of the rays. The specimen consisted of a "stair-case" of terne-coated sheets. Different intensities are obtained on the photographic film, across the image of the target, which correspond to the variation in thickness of specimen due to the overlapping terne strips.

Figure 4—Radiograph of Terne Plate "Stair-Case" Enlarged by X-rays. This Illustrates the Possibility of Detecting Differences in Absorbing Power of the Object for X-rays, as Accomplished in Natural Size Radiographs

Of interest from the standpoint of physics, in the present experiment, is the demonstration of the fact that X-rays eminate from all points of the target, though principally from the face. This was previously shown to be the case by Coolidge[2] who used the ionization method. Another point of interest is the fact that the spiral form of the filament of the cathode causes a variation in intensity of the resultant X-radiation from the face of the anode; the spiral nature of the latter may be discerned in Figure 3. The electrons from the cathode travel in straight lines despite inter-tube conditions.

Summary

The results of the experiment may be summarized as follows:

It has been found possible to obtain the image of the target of an X-ray tube on a photographic film by means of its own X-radiation if the pin-hole method of ordinary photography is resorted to. The size of the image of the target may be varied at will between wide limits. Through application of a "correlary" to the principle referred to, the image of an object introduced into the path of the target radiation (emerging from the pin-hole) may be obtained, and its degree of enlargement varied. Various opacities of the specimen will also be registered on the photographic film, as differences in intensities.

The writer hopes to inquire into the practicability of applying the method described to the study of fine structural features ("radiographically" speaking) which give rise to obscure, or incompletely understood, effects on the ordinary radiographic film.

[2] W. D. Coolidge and W. K. Kearsley, Jr., "High Voltage X-ray Work," *The American Journal of Roentgenology*, **9**, No. 2, 77–101 (Feb., 1922).

Correlated Abstracts

Dr. Gillett, the editorial staff and specially selected contributors will prepare abstracts reviewing the work recently reported pertaining to certain subjects. These reviews will take into consideration the work of a number of workers. The current literature will be covered in the Abstracts of Current Metallurgical Literature.

The Unknown Influence of Oxygen and Nitrogen on the Iron–Carbon System

Since a complete understanding of the iron–carbon system is the basis for an understanding of commercial plain carbon and alloy steels, it is of interest to note the accumulating evidence that our knowledge of this system is apparently not nearly as accurate or complete as is commonly supposed. Instead of having data on alloys of really pure iron with carbon, we have data on alloys contaminated with oxygen and nitrogen, and the effect of these elements cannot be neglected when exact knowledge is sought.

Many investigators use Armco iron as the purest iron available in quantity, but this iron contains, besides small amounts of carbon, manganese, sulphur and a trace of phosphorus, about 0.03% to 0.06% of oxygen. This latter impurity is often the one present in largest amount. Herty's[1] work on the physical chemistry of steel making shows clearly that any low carbon steel prepared by melting in the usual way must contain oxygen, in larger amount as the carbon content is reduced. By the addition of strong deoxidizers, such as aluminum, the FeO may be reduced, with the formation of the oxide of the added element. But Al_2O_3 is now pretty definitely proven to alter the behavior of the alloy on carburizing. In the study of "normal" and "abnormal" carburizing steels the action of FeO or other oxides certainly cannot be neglected. Harder[2] has found indications that the cementite solubility line Acm has different positions for different steels. It appears more than probable that the oxygen content may be a large factor in determining its position. As a matter of fact, the position of the Acm line was determined many years ago with methods and apparatus which are crude according to present day standards, and no recent re-determination has taken into account the oxygen content or the nature of the oxides present.

Gat[3] went so far as to postulate an oxygen-iron-carbon compound in certain abnormal steels. While the indications are that his observations are based on the appearance of an apparent constituent in his specimens whose presence may have been due to questionable metallographic technic, yet the question of the effect of oxygen still remains.

Guthrie[4] and Wozasek find that in gas carburizing there must be a little oxygen present, else carburizing is very slow. Thus, there is evidence from several sources that oxygen affects the solubility and rate of solution of carbon in austenite.

Grossman[5] suggests that the solubility of carbon in ferrite is also affected by oxygen, and there is experimental evidence to indicate that this may be the case.

Another possible effect of oxygen is suggested by Langenberg and Grossman[6] who claim much improved properties for very low carbon steel (less than 0.05% C) whose oxygen content is controlled so as not to exceed 0.03%. They ascribe intergranular brittleness (red shortness and poor transverse ductility) to intercrystalline oxygen-bearing films. This is not in accord with the findings of Cain[7] for iron, or of Merica and Waltenberg[8] for nickel, who found that these metals were not made red-short by oxygen alone. That there must be a field in the iron-carbon diagram for a solution of carbon in ferrite was stated by Yensen[9] and also recognized by Jeffries.[10] Whiteley[11] discussed this, and Hanson, in the discussion of Whiteley's paper, gave a tentative diagram. The diagram (see line MN, Figure 1) shows the possibility of a type of precipitation-hardening, such as occurs in duralumin and the work of Masing and Koch[12] indicates that this does occur. Since the phenomenon of spherodization depends on the diffusion of carbon in ferrite there is a good commercial reason for seeking better knowledge of this part of the iron carbon diagram and of the effect of oxygen upon it.

Recent work of Köster[13] on the duralumin type of hardening of low-carbon steels assumes that the material responsible for precipitation hardening is Fe_3C, but in discussion Fry pointed out that compounds of iron with nitrogen, oxygen or sulphur may all act similarly.

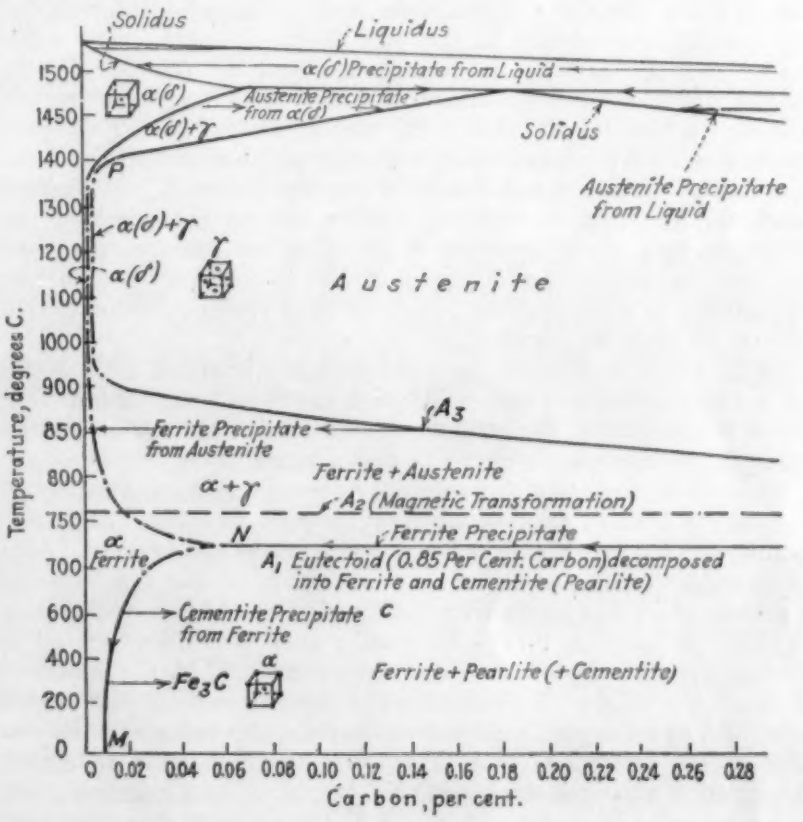

Figure 1—Constitutional Diagram for Fe-C. Yensen

Yensen[14] not only incorporates a field for solubility of carbon in ferrite in his iron-carbon diagram* (Figure 1), but raises the question whether *pure* iron has any allotropic transformations at all, and whether A_2 and A_3, as well as A_1, may not disappear when both carbon and oxygen are absent.

Yensen found that when he added to a particular sample of electrolytic iron 0.06% C, which he assumed was just sufficient to react with the oxygen present, leaving neither carbon nor oxygen in the iron after vacuum fusion, the magnetic permeability of the resulting iron was higher than had ever been obtained

[1] C. H. Herty, Jr., and G. R. Fitterer, "The Physical Chemistry of Steel Making," Carnegie Inst. of Tech., Min. & Met. Invest., *Bull.* **36**, (1928).

[2] O. E. Harder, L. J. Weber and T. E. Jerabek, "Studies of Normal and Abnormal Carburizing Steels, *Trans. Am. Soc. Steel Treat.*, **13**, 961 (1928).

[3] J. D. Gat, "Normality of Steel," *Trans. Am. Soc. Steel Treat.*, **12**, 376 (1927).

[4] R. G. Guthrie and O. Wozasek, "Gas Carburization of Steel," *Trans. Am. Soc. Steel Treat.*, **12**, 853 (1927).

[5] M. A. Grossman, "On Oxygen Dissolved in Steel and Its Influence on the Structure," *Trans. Am. Soc. Steel Treat.*, **15**, 1 (1929).

[6] F. C. Langenberg and M. A. Grossman, U. S. Patent, 1,695,594, December, 1928.

[7] J. R. Cain, "Influence of S, O, Cu and Mn on Red-Shortness of Iron," Bureau of Standards, *Tech. Paper* **261** (1925).

[8] P. D. Merica and R. G. Waltenberg, "Malleability and Metallography of Nickel," Bureau of Standards, *Tech. Paper* **281** (1925). See also A. Wimmer, "Uber den Einfluss des Sauerstoffs auf die Physikalischen und Technischen Eigenschaften des Flusseisens," *Stahl und Eisen*, **45**, 73 (1925).

[9] T. D. Yensen, "The Magnetic Properties of the Ternary Alloys, Fe-Si-C," *Trans. Am. Inst. Elec. Eng.*, **43**, 145 (1924).

[10] Z. Jeffries and R. S. Archer, "The Science of Metals," **1924**, 308.

[11] J. Whiteley, "The Solution of Alpha-Iron and Its Precipitation, *Jour. (Brit.) Iron and Steel Inst.*, **116**, 306 (1927).

[12] G. Masing and L. Koch, "Duraluminartige Vergütung bei Eisen-Kohlenstoff Legierungen," *Wiss. Veröffentlich. Siemens-Konzern*, **6**, 202 (1927).

[13] W. Köster, "Der Einfluss einer Wärmebehandlung unterhalb A_1." *Archiv f. Eisenhüttenwesen*, **2**, 503 (1929).

[14] T. D. Yensen, "Pure Iron and Allotropic Transformations," *Am. Inst. Min. & Met. Eng., Tech. Pub.* **185** (1929).

* Some modification of this diagram may result from the suggestions made by Dr. Anson Hayes in discussion at the meeting.

for unalloyed iron. He has since found[15] that on standing in the air, the permeability of this iron decreased, and microscopic examination showed oxide inclusions, indicating that oxygen was taken up at room temperature.

Stevens[16] cites a test in which silicon steel transformer sheet scrap was remelted under hydrogen in an induction furnace for the purpose of lowering the oxygen content. Sheets made from the remelted scrap are said to have shown 7% less core loss than the original metal.

Investigators, even in recent times, generally refer to electrolytic iron, as deposited, or after vacuum fusion, as "pure iron."[17] As Yensen points out, however, electrolytic iron usually contains about 0.003% to over 0.01% carbon and a very considerable amount of oxygen—Yensen finding up to 0.40% oxygen in some samples. Carefully acid-washed electrolytic iron, remelted in vacuo, can be produced with less than 0.01% oxygen, but, without special precautions, the mere use of electrolytic iron does not insure purity.

Thus it becomes evident that the observations on which the classic binary iron-carbon diagram are based were really made on the ternary iron–carbon–oxygen system, in which the oxygen content was an unknown variable.

The solubility of oxygen in solid steel is doubtless very low, but increases with increasing temperature, the ferrite-oxygen solubility curve would be presumably quite similar to that for ferrite and carbon. Hence it is somewhat of a question how much of the effect of quenching from below A_1 and of subsequent tempering or aging upon the properties of low-carbon steels is due to carbon and how much to oxygen. Köster[18] quenched low-carbon steels from various temperatures and determined color carbon by the Eggertz method in the quenched specimens. The differences between carbon by combustion and by the colorimetric method give a curve for carbon solubility which agrees with that usually taken for solubility of carbon in ferrite. This gives some basis for his assumption that the physical properties noted are due to variation in amount of dissolved carbon. Though no analyses for them are given, Köster admits that oxygen and nitrogen may stand in close relation to the phenomena which he ascribes mainly to retention of carbon in solution on quenching from 680° C., and formation, rejection and coagulation of cementite on aging or tempering.

With a 0.10% C steel the aged material is about 50% higher in tensile strength, yield point and hardness, and about 50% lower in elongation, than the material tested at once after quenching. The stress-strain curve is also altered.

It is probable that the solubility, or the rate of solution, of carbon or FeO in iron is affected by cold working. Johnson[19] points out that Armco iron has a tendency to age-harden. After 82% reduction in thickness by cold-rolling, it has a scleroscope hardness of 58 two hours after rolling, and of 64 after twelve days.

Pfeil[20] studied a 0.11% C steel which was decarburized to different degrees by heating in hydrogen at 950° C. for periods of 6 days to 5 weeks. Presumably the oxygen content was altered also, but, as no oxygen analyses were given, this remains unknown. The 0.11% C steel after cold drawing to 23 to 60% reduction, increased in strength some 5000 lbs./sq. in. after a month at room temperature. With around 0.02% C the increase was somewhat greater, but when the carbon fell below 0.003% the strength increase on aging was practically zero, which indicated that the effect was due to carbon solution and precipitation. But on annealing the completely decarburized material in an oxidizing atmosphere, the ability to age-harden was restored. Metallographic examination showed oxide particles present and the conclusion was drawn that some oxide was in solution, was made less soluble by cold work, and that the aging process for the oxidized material is the precipitation of oxide particles which harden the metal by slip-interference.

Bolsover[21] has studied the behavior of mild steel over the carbon range from Armco iron to 0.20% carbon, and found that, if the iron is deformed and reheated to about 250° C., the impact values are lowered greatly—say, from 90 to 10 ft.-lbs. in the Izod impact test at room temperature. The toughness reappears at higher testing temperatures and is dependent on the reheating temperature.

He ascribes this phenomenon to sub-microscopic recrystallization rather than to a duralumin type of precipitation of some hardening compound, but, since he finds the brittleness to be greatly increased by increase in phosphorus and gives no determinations for any of the gaseous elements, his work raises the question whether the matter is not more complex and whether the interaction of carbon, phosphorus, oxygen and nitrogen may not have to be considered in the study of this phenomenon.

In duralumin there is a tendency, under some conditions of aging or accelerated aging, for the hardening particles, as they come out of solution, to collect at the grain boundaries.

There is some evidence to indicate that in the austenitic stainless steel containing 18% Cr and 8% Ni a content of 0.07% C is critical. Above this percentage of carbon, on quenching from 1185° C. and reheating to 535° C., a precipitation, presumably of carbides, occurs at the grain boundaries which embrittles the steel. By analogy with other precipitation phenomena, it may be that the oxygen content will affect this precipitation also.

In ordinary steel, it is claimed[22] that at high temperatures and pressures, in the presence of reducing gases such as hydrogen, steel containing oxygen is corroded at the grain boundaries, the reaction being analogous to that with copper containing oxide.

Propensity toward "caustic embrittlement" of boiler plate is sometimes ascribed to oxygen content. Indeed, every obscure ailment of steel is, in the absence of evidence to the contrary, ascribed to the effect of one or another gaseous element.

Fry[23] claims that some low carbon steels, boiler plate, for example, are sensitive to aging, i. e., the material, deformed at room temperature and allowed to rest at room temperature, or heated for a short time to, say, 200° C., becomes notch-brittle, and sensitive to chemical corrosion, as by soda solution. These appear to be grain-boundary phenomena. Fry refers to a melting method described in another patent application, on which the patent has not yet been issued, for producing steel insensitive to aging, which may perhaps refer to control of oxygen content. He claims, however, that even a steel which is normally sensitive to aging, may be made insensitive by heat-treatment, through quenching at above 650° C. and tempering at a temperature below that of the quench, but below 750° C. Fry gives an example of a steel with 0.08% C, 0.004% N, 0.041% O, whose notch toughness after cold working is vastly improved by the heat-treatment, which presumably precipitates the hardening compounds within the crystals rather than at grain boundaries.

Many new questions are thus arising in regard to low carbon steels, deep drawing stock, ingot iron and wrought iron which cannot be answered without considering not only the carbon content, but the oxygen and nitrogen content as well.

Indeed, a similar situation to that for oxygen, exists as to nitrogen. The iron–nitrogen system, which is of increasing commercial interest to-day as the base line for the study of nitrided steels, is by no means thoroughly understood. Very small amounts of nitrogen are present in commercial steels, and, aside from some claims of enthusiasts who advocate direct reduction of sponge iron and give as one reason for the alleged superiority of sponge iron as a raw material the fact that it has not been melted in presence of nitrogen during smelting and is thus said to be nitrogen free, very little consideration has been given to its effect.

Dean, Day and Gregg[24] find that electrolytic iron melted in air takes up around 0.07% nitrogen, and hardens on being subjected to the duralumin type of heat treatment (previously indicated as a possibility by the Fry diagram for iron and nitrogen), while electrolytic iron melted in vacuum, and hence not containing nitrogen, does not harden.

Since oxygen determinations were not given, the proof that oxygen may not play a part in the phenomena noted is not complete, yet microscopic evidence as to the disappearance of nitride needles on quenching, combined with electrical resistance observations indicate that nitrogen is probably concerned.

[15] Personal communication.

[16] C. R. Stevens, "The Induction Furnace in the Brass Foundry," *Fuels and Furnaces*, **7**, 547 (1929).

[17] Compare A. Sauveur, "The Gamma-Alpha Transformation in Pure Iron," *Am. Inst. Min. & Met. Eng., Tech. Pub.* **169** (1929). G. K. Burgess, and J. J. Crowe, "The Critical Ranges A_3 and A_2 of Pure Iron," *Trans. Am. Inst. Min. Eng.*, **47**, 665 (1914).

[18] See Ref. (13).

[19] F. Johnson, Discussion, *Jour. Inst. Met.*, **60**, 396 (1928).

[20] L. B. Pfeil, "The Change in Tensile Strength Due to Aging of Cold-Drawn Iron and Steel," Iron and Steel Institute, Preprint **6**, Sept., 1928, Meeting.

[21] G. R. Bolsover, "Brittleness in Mild Steel," Iron and Steel Institute, Preprint **3**, Spring Meeting, 1929.

[22] I. G. Farbenindustrie Aktiengesellschaft (J. Y. Johnson) British Patent 293,077, July 3, 1928.

[23] A. Fry, U. S. Patent 1,700,674, January 29, 1929.

[24] R. S. Dean, R. O. Day and J. L. Gregg, "Relation of Nitrogen to Blue-Heat Phenomena in Iron and Dispersion Hardening in the System Iron-Nitrogen," *Am. Inst. Min. & Met. Eng., Tech. Pub.* **193** (1929).

The interesting observation was made that Armco iron, freed from nitrogen by heating at 1100° C. in hydrogen for 12 hours (this should also remove carbon and oxygen so it does not entirely prove that nitrogen is concerned rather than carbon or oxygen), not only did not harden on reheating after cold work, but also failed to show the increase in tensile strength at 100° C. to 300° C. (the blue-brittleness or temper-brittleness range). The conclusion is therefore drawn, that the behavior of ordinary steel in the "blue heat" range may be due to the presence of tiny amounts of nitrogen instead of being characteristic of the iron-carbon alloys themselves. Oxygen from moisture in the NH_3-N_2-H_2 mixture used for nitriding, is suspected of giving rise to a special metallographic constituent in the "case" of nitrided steels. The physical properties of the case may be related to this constituent.

Rawdon, Hidnert and Tucker[25] have found some indications that hydrogen may affect the thermal critical points of iron. Thus it becomes obvious that any contamination of the iron-carbon alloys by oxygen from the refractory container or from the atmosphere, or by nitorgen or hydrogen, may affect the properties of the iron–carbon system.

When one leaves the field of relatively pure iron and goes to such complex materials as malleable iron and pig iron, there is evidence that oxygen, probably present as complex silicates rather than, to any large extent, as FeO itself, may have a profound, though still little-understood, effect.

Schenck[26] and Schwartz[27] point out that, in the presence of CO or CO_2, traces of oxygen are taken into solid solution in ferrite or austenite. For such solutions the terms oxoferrite and oxo-austenite have been introduced. Just how they differ from oxygen-free ferrite and austenite is not certain, but the presence of oxygen is thought to have a decided bearing on problems in malleable iron.

Forbes[28] points out that unsatisfactory malleable iron results when furnace operation is abnormal and oxidation is probable. If such castings after malleableizing are reheated at 490° C. they are brittle and show a white fracture. Heat-treatment, i. e., heating to 685° C. and quenching through the 490° C. range makes the castings ductile. This again appears to relate to a duralumin type of hardening, presumably primarily by carbon, but probably this is affected by oxygen content. In discussion, Marshall suggested that the effect of nitrogen on carbide precipitation from ferrite could not be neglected, and may be as important as that of oxygen.

Herty and Gaines[29] point out probable effects from oxygen as silicates. Boegehold[30] shows preliminary evidence, but sufficient to justify further study, that the moisture content of the blast in the blast furnace and the cupola, and the rate of travel of the stock through the blast furnace, both of which variables are assumed to alter the oxygen content, may control the ability of the iron to chill, its piping shrinkage on solidification, its fluidity and its machinability.

Much of the uncertainty on the effect of oxygen, nitrogen and hydrogen is due to the difficulty of quantitatively determining these elements. Oberhoffer[31] and collaborators (and since Oberhoffer's untimely death, Hessenbruch) at Aachen, and Jordan[32] and Herty[33] and their associates in the Bureau of Standards and Bureau of Mines in this country, have studied various methods for the determination of these elements.

While the methods are tedious, and not all the difficulties have yet been overcome, they are steadily becoming more suitable for general use. Such laboratories as those of the Union Carbide and Carbon Research Laboratory, General Electric Co., Central Alloy Steel Corporation, American Rolling Mill Co., Watertown Arsenal, etc., are using the methods regularly, and much more information will be forthcoming in the course of time.

It seems possible, with the methods now available, to go back to fundamentals and redetermine the iron-carbon equilibrium diagram with due regard to the effects of the "pestiferous" impurities which, while not exactly vitiating the earlier results make them too inexact to meet satisfactorily all the demands for precise information to-day.—H. W. GILLETT.

[25] H. S. Rawdon, P. Hidnert and W. A. Tucker, "Some Effects of Hydrogen on Steel and Their Bearing on a Reported Transformation at 370° C.," *Trans. Am. Inst. Steel Treat.*, **10**, 233 (1926).

[26] R. Schenck, "Gleichgewichtsuntersuchungen über die Reduktions, Oxydations und Kohlungsvorgänge beim Eisen," *Zeit. für. Anorg. und Allgem. Chem.*, **167**, 19, 315.

[27] H. A. Schwartz, "Oxidation Phenomena During the Annealing of Malleable Cast Iron," *Trans. Am. Faraday Assn.*, **36**, 385 (1928). See also H. Sawamura, "Influence of Various Gases on the Graphitization of White Iron," *Iron and Steel*, **14**, 241 (1928).

[28] D. P. Forbes, "Practical Aspects of White-Fracture Malleable," American Foundrymen's Association, Preprint **29–22**, 397 (1929).

[29] C. H. Herty, Jr. and J. M. Gaines, Jr., "Unreduced Oxides in Pig Iron and Their Elimination in the Basic Open Hearth Furnace," *Am. Inst. Min. & Met. Eng., Tech. Pub.* **165** (1929); *Blast Furnace and Steel Plant*, **17**, 418 (1929).

[30] A. L. Boegehold, "Quality of Pig Iron and Castings as Affected by Blast Furnace Practice," Am. Foundrymen's Assn., Preprint **29–5** (1929).

[31] P. Oberhoffer and W. Hessenbruch, *et al.*, Various Articles—*Stahl und Eisen*, **45**, 1341, 1379 (1925); **47**, 1536, 1540 (1927); **48**, 486 (1928); *Archiv. für Eisenhüttenwesen*, **1**, 583 (1927); *Rev. de Metallurgie*, **26**, 93 (1929). Compare also O. Meyer, "Über den heutigen Stand der Bestimmung von Sauerstoff im Stahl und Eisen," *Zeit. f. Angew. Chemie.*, **41**, 1273, 1295 (1928)

[32] L. Jordan, *et al.*, Various Bureau of Standards papers, *Sci. Papers* **457**, (1922); **514**, (1926); **563** (1927); Res. Paper **25** (1928); *Trans. Am. Foundrymen's Assn.*, **1925**, 431.

[33] C. H. Herty, Jr., *et al.*, "A Study of the Dickenson Method for the Determination of Non-Metallic Inclusions in Steel," Carnegie Inst. of Tech., Min. & Met. Invest., *Bull.* **37** (1928).

Many Days Saved by New Malleableizing Process

A new short-cycle annealing process*for the production of malleable iron castings is announced by the General Electric Company. A number of advantages have resulted from the use of the new malleableizing process, particularly a saving of many days. Details of the new method were worked out in the Erie foundry of the General Electric Company. After ascertaining the proper temperatures and time involved to effect the required changes in the metal, it was found that, by the use of electric furnaces, a cycle of operations which was as near as possible to the ideal could be obtained.

Three electric annealing furnaces are used for this purpose at the Erie plant, each rated 325 kilowatts and using nickel-chromium ribbon resistor heating elements. The connections are arranged to allow a power input of 52, 170 or 325 kilowatts as desired. The capacity of the installation is 100 tons of castings per week.

In operation the hard castings, of commercial composition, are packed on the car bottoms or without iron plates or boxes, depending on the nature of the load. It was found that best results were obtained by stacking the charge directly on the floor of the car.

The charge is then placed in a furnace and heated to a sufficiently high temperature to effect solid solution of free cementite, whereupon the charge is transferred, without removing from the car, to another furnace for cooling. In this furnace the castings are brought to a temperature below 750° C. which is held for approximately four hours after which the temperature is suddenly lowered a few degrees and maintained at this lower temperature for another four hours, when this step is repeated. The castings are then transferred either to a cooling furnace or into the air, or they may be quenched immediately with increased strength and without brittleness. The average time for a six-ton anneal is between 28 and 30 hours.

Tests taken by the General Electric Company show that the tensile strength, yield point and other characteristics are practically the same with the short-cycle anneal as with the older methods. It was found that the short-cycle malleable iron machines were better than the long-cycle product, and show no signs of framing or reversion. Very little skin is found and the castings clean somewhat easier than the old type of product. The castings may be galvanized without embrittlement and without previous or subsequent treatments. Warpage is also found to be reduced.

The advantages as found by the General Electric foundrymen are as follows: (1) The elimination of boxes and packing material, reducing labor involved, eliminating hard cleaning if desired and allowing much cleaner operation. (2) Reduction of time, resulting in less inventory, shorter deliveries and a saving in space and furnace investment. (3) The control of the anneal by varying the cycle, to meet variation in metal composition. (4) Lower cost.

* I. R. Valentine, "Malleable Iron—Short Cycle Anneal," this issue, page 233.

Abstracts of Current Metallurgical Literature

In this section, abstracts of metallurgical articles in various publications will appear. These abstracts are not critical, but merely review developments as they are recorded. Every effort will be made to report on all articles as soon as possible.

Many laboratories do (and more laboratories would if they appreciated its value) adopt the policy of clipping, pasting on cards and filing abstract literature. In order to help those who wish to do this, additional copies of METALS & ALLOYS *will be sent to any subscriber for $2.00 per copy per year extra. The time required for clipping, pasting and filing is so much less than the time needed to transcribe abstracts that a distinct saving can be made by ordering extra copies.*

PROPERTIES OF METALS

The Expansion of Zinc at Increasing Temperature. (Die Ausdehnung des Zinks be isteigenden Temperaturen.) O. BAUER & H. SIEGLERSCHMIDT. *Mitteilungen der deutschen Materialprufüngsanstalten*, Sonderheft V, 1929, pages 62–63.

An anomaly in the expansion curve of zinc seems to point to a transformation point at 170° C. HA

Influence of Pressure on All Sides upon Metallic Conductivity at Low Temperature. (Der Einfluss allseitigen Druckes auf die metallische Leitfähigkeit in tiefer Temperatur.) H. J. SEEMAN. *Physikalische Zeitschrift*, May 1, 1929, pages 256–258.

Summing up the previous investigations, the author describes the equipment and method used for the determination of the influence of pressure upon metallic conductivity. Attention is called to the fact that temperature must be kept constant. The measurements were performed on copper. The pressure coefficient at ordinary temperatures between 50 and 150 kg./cm.^{2} was found to be $\gamma = -2.14\ (+\ 0.013) \times 10^{-6}$ which value increases at −195° C. in liquid nitrogen to -5.17×10^{-6}. EF

PROPERTIES OF NON-FERROUS ALLOYS

Hardness Relationships and Physical Properties of Some Copper Alloys. G. H. DAVIS AND E. L. MUNSON. Preprint No. 47, *Proceedings American Society for Testing Materials*, 29 (2), (1929), 12 pages.

The tensile strength of rolled Cu-Zn, Cu-Sn and Cu-Zn-Ni alloys cannot be precisely deduced from the Brinell or Rockwell hardness. For the same hardness the strength varies with the composition and with the annealing treatment given between stages of the rolling process. The complete history of the specimen must be known so that its hardness may be compared with a predetermined curve for the hardness-strength relation of metal of the same composition and history, before the strength can be deduced from the hardness. The facts are brought out by many curves and the conclusion is justified that no single conversion curve can be plotted that will serve for different alloys. HWG

Silver Tin Alloys and Amalgams. (Ueber Silber-Zinn Legierungen und Amalgame.) O. LOEBIG AND L. NOWACK. *Metallwirtschaft*, July 5, 1929, pages 654–655.

The poisonousness of Ag-Sn amalgam fillings in dental use attracted the interest of the metallurgists. The authors give a survey of the nine main investigations with those of Murphy, Guertler and Bonsack, Rosenhain, Tammann and Dahl, Sterner and Rainer among the most remarkable ones, dealing with crystallographic phases, strength and other mechanical properties, aging effects, hardening of amalgams. The unique method of Rosenhain for the investigation of liquid amalgams by freezing in a mixture of carbonic acid, snow and acetone deserves particular mention. Corrosion tests in distilled water, sodium chloride solution and lactic acid proved the dissolution of Sn and not of Hg. The elimination of the SnHg solid solution and a most suitable alloy of 60 percent Ag are recommended. EF

On the Absence of Change in Magnetic Susceptibility with Crystallization in Strong Magnetic Fields. L. A. WELO. *Physical Review*, July 15, 1929, pages 296–299.

Lead, tin, bismuth, nickel chloride and potassium ferricyanide were crystallized in strong magnetic fields and examined for changes in the magnetic susceptibilities. The changes, if any, were not more than 9.16 percent in Pb, 0.29 percent in Sn, 0.32 percent in Bi, 0.42 percent in $NiCl_2$ and 0.04 percent in $K_3Fe(CN)_6$.

Application of Statistical Methods to a Set of Metallurgical Data. Basis for Analysis of Test Results of Die-Casting Alloy Investigation. W. A. SHEWHARD. Appendix 1 to report of subcommittee XV (on die-castings) of Committee B-2 (on non-ferrous metals). Preprint 19, in *Proceedings American Society Testing Materials*, 29 (1), (1929), 11 pages.

In the A. S. T. M. test program on die-castings 80,000 castings will be tested, and 20,000 tests on aluminum alloys have been completed. Statistical methods are applied to the data. By use of mathematical criteria and distribution curves it can be shown whether variations in test results are within the limits due to chance or whether some variable should be more closely controlled. The application of the methods to the actual die-casting data is explained as a practical illustration, which makes it easier reading than some of the more abstract discussions of statistical analysis. HWG

Experiments to Increase the Strength of Lead-Bearing Metals. (Versuche zur Erhohung der Festigkeit von Bleilagermetallen.) CH. L. ACKERMANN. *Metallwirtschaft*, May 3, 1929, pages 422–423.

Previous investigations by O. W. Ellis (Am. Met. Market, May, 1928) on the improvement of lead-bearing metals of the system Pb–Sb–Sn by additions of thallium are discussed critically. The author presents his own experiments with 20 alloys for bearing metals in a tabular form containing the values of hardness, impact work and reduction in height at the beginning of crack formation, which determine the value of a bearing metal. Hardness could not be increased by additions of thallium but a decrease could be noticed on replacing all tin by thallium. Impact work and height reduction also could not be influenced by thallium. Even relatively high concentrations up to 10 percent of thallium are practically without any effect in high lead-bearing metals containing small amounts of tin, so that industrial application is not advisable. EF

On the Photoelectric Effect of Al and Its Amalgams. (Ueber den photoelektrischen Effekt des Al und seiner Amalgame.) A. SMITS AND H. GERDING. *Physikalische Zeitschrift*, May 15, 1929, pages 322–325.

Previous investigations along these lines with active and passive Fe failed due to absorbed gases. Al-amalgams exhibited photoelectric effects 4 and 5 times as strong as pure Al, due to changes in the inner state. Passive Al is not in the state of inner equilibrium. There is a lack of ions and electrons. Traces of Hg restore the equilibrium accompanied by a strengthening of the photoelectric effect. EF

Electric Conductivity, Thermal Expansion and Hardness of Magnesium-Zinc-Alloys. (Die elektrische Leitfähigkeit, die thermische Ausdehnung und die Härte der Magnesium-Zink-Legierungen.) G. GRUBE AND A. BURKHARDT. *Zeitschrift für Elektrochemie und angewandte physikalische Chemie*, June, 1929, pages 315–332.

The systematic thermal investigation of Mg-Zn alloys confirmed first the constitutional diagram determined by Chadwick; two new horizontal lines of transformation were also found. Alloys with a composition close to the pure compounds show very great hardness. Test methods and results are given in detail and illustrated by many curves and diagrams. HA

What Happens When Steel Gets Tired. D. D. EWING. *Electrical World*, August 10, 1929, page 271.

A discussion of the fatigue of metals and of precautions necessary in design to minimize the danger. Means of securing fatigue data, and of showing the fatigue of rails and car axles are given. Six tables show several kinds of steel and 15 conclusions are listed regarding what happens when "steel gets tired." WHB

PROPERTIES OF FERROUS ALLOYS

Impact Testing of Cast Iron. H. BORNSTEIN. Preprint No. 35, for publication in *Proceedings American Society for Testing Materials*, **29** (2), (1929), 6 pages.

Transverse drop tests were made on broken halves of arbitration bars 1/4″ diam. supported so as to give a 4″ free span, by dropping a 100-lb. hammer midway between supports from 2″, 4″, etc., up to 10″, then by 1″ increments. Regular iron 3.30% total carbon, 0.50% combined carbon, 2.05% Si, 0.60% Mn, 0.35% P, 0.075% S broke at 6″ to 10″, average 7.2″. High test iron, 2.90% total carbon, 0.55% combined carbon, 2.25% Si, 1.25% Ni, 0.75% Mn, 0.08% P, 0.075% S broke at 11″ to 20″, average 16.2″. References are given to other work on impact testing of cast iron. HWG

Wear Testing of Cast Iron. A. A. BOEGEHOLD. Preprint No. 35, for publication in *Proceedings American Society for Testing Materials*, **29** (2), (1929), 11 pages.

A "universal" wear test, to indicate how any metal will wear under all conditions, is impossible on account of the various types of service in which wear takes place. There must be a special type of test for each type of wear, and it must represent service conditions as nearly as possible. Conclusions expressed by earlier investigators as to the effect of different compositions and structures of cast iron on wear are very contradictory, owing to the various kinds of tests used and the many variables affecting cast iron. To study wear of automobile engine cylinder irons a test specimen 3/10″ × 2 1/2″ was pressed against a rotating drum 8″ diam. × 2 1/2″ face under varying loads. With oil present, and a 5-volt circuit connected to the specimen and drum, it was possible by use of an oscillograph to show at what pressure the oil film broke down so as to allow metal-to-metal contact. When operating under such pressures that the oil film continually broke and reformed, wear took place but the periods of contact were so irregular that no two test runs could be compared. At such high loads that there was constant metal-to-metal contact, but in the presence of lubricating oil or kerosene, wear was considered to be too slow for test purposes, and recourse was finally had to running the test dry, without any lubricant. Cast iron varying in combined carbon from about 0.10 to 0.85% was run dry against a drum of 0.46% combined carbon, 180 Brinell, sliding 1600 ft./min. under a load of 12 lb./sq. in. The wear in the test decreased with increase in combined carbon. Permanent-mold iron of the same combined carbon wore very much faster than sand-cast iron of the same combined carbon, notwithstanding the prevalent idea that a fine-grained structure opposes wear. In actual practice in an air-cooled engine run 20,000 miles, cylinders of unannealed sand-cast iron 0.51% combined C, 212 Brinell; of soft sand-cast iron 0.40% combined C, 121 Brinell; of unannealed permanent-mold iron 0.38% combined C, 223 Brinell; and of annealed permanent-mold iron 0.06% combined C, 185 Brinell showed wear varying only from 0.0015″ to 0.0020″. Thus, with good lubrication, it was immaterial, from the point of view of wear, which iron was used. Eight cars of different makes were each run 20,000 miles and the cylinder wear measured and compared with the chemical analysis of the cylinder iron. The wear decreased as the silicon content decreased, a block with 2.82% Si wearing 0.0135″ and one with 2.02% Si only wearing 0.001″. While other factors such as design and amount of road dust entering lubrication come in, this does line up with the dry wear tests in which combined carbon was the variable studied. The amount of abrasive material entering the cylinders is a great factor in the amount of wear, as is faulty lubrication. The latter will be more disastrous to irons low in combined carbon. HWG

Properties of Various Tool Steels. A. R. PAGE. *Heat Treating and Forging*, July, 1929, pages 843–845.

Address delivered before Birmingham Metallurgical Society. Great advances have been made in the last 20 or 30 years in production and heat-treatment of tool steel and in selection of material for a particular purpose. Composition of high speed steels has been largely modified. High speed steel becomes harder on tempering which also tends to remove strains and increase toughness at the same time. It has the power of retaining its hardness when hot, and its mechanical strength at high temperatures. There are two types of plain carbon steels, water hardening, in which manganese should not exceed 0.35%, and oil hardening, in which manganese reaches 0.8–1.0%. Presence of small amounts of chromium increases hardening power of the steel. Alloy tool steels containing fairly high percentages of carbon and about 4–5% tungsten with a small amount of chromium have extensive application. Electric furnaces are almost ideal for heating. Tool steel must be clean, with a minimum amount of segregation. MS

The Raising of Apparent Elastic Limit by Straining and Aging. (Recherches sur le relevment de la limite elastique apparente par traction et vieillissment.) J. GALIBOURG. *Revue de Metallurgie*, June, 1929, pages 334–339.

If a bar of steel is stretched in a tensile machine above elastic limit, the load removed and then applied again until the specimen is broken, the amount of the original stress will become elastic limit of the second operation. After letting it rest before pulling a higher apparent elastic limit will be found. Soft steels were normalized to the same physicals and after stretching to 33 kg./mm.² were kept at different temperatures from one minute to 36 days and then pulled to fracture. The yield point recorded reached maximum of 39 kg./mm.² after 36 days at 12°, 420 minutes at 50° and after 3 minutes at higher temperatures. From the curves plotted a formula for secondary elastic limit is deduced. A set of normalized bars was stretched at its elastic limit, the next just under the breaking point and several at intermediate values. Aging at the temperatures from 12 to 18° lasted from one to 53 hours. The original Y. P. was 28.5 kg./mm.² and U. S. 41.5 kg./mm.² After 2.5 hours a specimen stretched to 28.5 kg./mm.² gave elastic limit of 37.75 kg./mm.² and a specimen stretched to 41 kg./mm.² had elastic limit of 45.2 kg./mm.² after 23 hours' aging. The length of curves corresponding to apparent elastic limit on stress-strain diagram is much shorter than for true elastic limit. The same effect takes place with Ni but at higher temperatures. JDG

Properties of Materials at High Temperatures. "Creep" Tests on Low-Carbon Steels. *Iron and Coal Trades Review*, July 12, 1929, pages 48, 49.

Extracts from Report No. 14 by R. G. BATSON AND H. J. TAPSELL on "The Strength at Elevated Temperatures of Low-Carbon Steels for Boiler Construction." Short-time tensile tests and prolonged loading tests at elevated temperatures have been carried out to determine: (1) the limiting temperatures for "creep" corresponding to a range of stress from 0.5–4.0 tons per sq. in. on boiler and super-heater tubes and on bar steel similar to steel used for tubes; (2) the limiting "creep" stresses corresponding to a temperature range of 400° C. to about 530° C. on superheater and steam drums. Four tables show: chemical analyses of samples tested, results of short-time tensile tests, stresses applied and results of "creep" tests carried out on uncoated low-carbon steels. Steady daily increase in thickness of oxide is not proven, but results indicate that oxidation increases rapidly above 570° C., while at 647° C. it becomes excessive on unprotected material. Some evidence of inter-crystalline cracking was found at certain temperatures, limiting the applicability of such steels where long exposures under stress at high temperatures is met. It is probable that up to 500° C. the initial limit of proportionality is correctly determined by a short-time test. Any applied stress in excess of the initial limit of proportionality results in some strain-hardening, which may or may not later be nullified by temperature softening, depending on whether the limiting "creep" stress is less or greater than the initial limit of proportionality. The 0.1% carbon steel appears to be more susceptible to strain and hardening at 500° C. for similar rates of strain than the normalized 0.17% carbon steel. So long as strain-hardening occurs, the elongation is practically general. A slight yielding at one point causes local hardening and the transference of the yielding to another point and finally rapid local contraction and failure at the weakest spot. When little or no strain-hardening is evidenced by the strain-duration curves, the elongation is found to start locally at the weakest spot, but also occurs at a decreasing rate toward the end of the test piece. The original report concludes with a reference to superheater and steam drums. WHB

The Influence of Composition and Heat-Treatment on the Properties of High-Speed Steels as Cutting Tools. (Om Sammansättningens och varmbehandlingens inverkan pa snabbstalens egenskaper som skärande verktyg.) G. WALLQUIST. *Jernkontorets Annaler*, July, 1929, pages 305–350.

The publication is a thorough treatise on the influence of composition and heat-treatment on the qualities of high-speed steel. In the preface the manufacture and development of these materials is given. Furthermore the theories of hardening are discussed. The investigations of the author tend to show in how far the cutting properties are influenced by the composition and heat-treatment. The tools were heated in a $BaCl_2$ salt bath and thereafter quenched in oil. With the tools thus prepared annealed ball bear-

ing steel of the following composition was cut: C: 1.00%, Si: 0.30%, Mn: 0.30%, Cr: 1.50%, Brinell hardness: 174–179. The cutting investigations were carried out according to Taylor's "Break-Down" test. Cutting speed 82 feet per minute, thickness of chip $^1/_8$", feed: $^5/_{128}$". The investigation included three series of tests: 1. Comparing cutting tests of 15 different steels to study the influence of composition. 2. The influence of hardening temperature on hardening and cutting qualities. 3. The influence of drawing temperature: (*a*) With each of the 15 steels 5 samples were investigated; 1 specimen hardened at 1250° C., 1 at 1275°, 2 at 1300°, 1 at 1325° C. The drawing temperature in each case was 590° C. The results are given in Table 1. (*b*) The results of the second series are to be found in Table 2. (*c*) In order to examine the influence of drawing temperature on the change of cutting qualities 4 of the steels were tempered from 560 to 640° C., as shown in Table 3.

Summarizing statements: The increase of tungsten to a certain degree improved the cutting capacity. A greater influence was shown by molybdenum. The largest influence was that of vanadium on chromium-tungsten steels. Cobalt or cobalt and molybdenum together improve the chromium-tungsten-vanadium steel still more. In high alloyed steels the proper content of carbon is most important and should not be too low. Increasing or decreasing the drawing temperature by about 25° C. decreases the cutting properties to 65–85% of the maximum in the proper treated steel. A diminishing influence by exceeding the drawing temperature. The time of heat-treatment is also of great significance. A greater hardness seems to result in better cutting qualities, but a direct relation between hardness and best cutting properties could not be verified. The present paper is in accordance with previous American and German investigations on this subject which is referred to abundantly.

Table 1—Influence of Composition of Hardness and Hardness and Cutting Properties

Steel	Analysis, %								Average Value of 2 Samples Hardened at 1300° C., Drawn at 590° C.		Average Value of 5 Samples Hardened 1250–1325°, Drawn at 590° C.	
	C	Si	Mn	Cr	W	V	Mo	Co	Rockwell Hardness	Cutting Time, Min.	Rockwell Hardness	Cutting Time, Min.
D1	0.47	0.58	0.36	2.57	10.7	0.36	..	..	63.0	1.28	62.8	1.07
D2	0.65	0.23	0.30	4.08	15.8	0.17	..	..	64.2	1.40	64.0	1.35
D3	0.74	0.34	0.26	3.56	15.8	0.35	0.26	..	64.5	1.72	64.4	1.35
D4	0.78	0.21	0.30	3.91	16.2	0.87	0.80	..	66.0	2.94	65.7	2.42
D5	0.80	0.23	0.36	3.94	19.1	0.90	..	..	65.9	3.33	65.6	2.72
D6	0.80	0.19	0.52	3.74	15.3	0.79	0.72	..	65.9	3.33	65.6	2.85
D7	0.75	0.10	0.48	3.87	17.7	0.77	..	..	65.4	4.17	65.2	2.95
D8	0.73	0.17	..	4.69	19.3	0.86	..	1.69	65.3	4.12	65.2	3.32
D9	0.69	0.27	0.35	4.37	13.2	1.56	..	..	65.2	3.82	65.0	3.74
D10	0.71	0.23	0.29	4.19	17.6	1.21	0.73	..	65.7	6.02	65.4	4.12
D11	0.73	0.28	0.34	4.46	18.0	1.52	..	..	65.0	5.33	64.7	4.22
D12	0.76	0.18	..	4.82	17.1	1.09	0.97	6.10	65.7	6.45	65.4	5.02
D13	0.72	0.30	..	4.56	17.6	1.12	0.44	4.80	65.9	7.42	65.6	5.65
D14	0.90	0.31	..	5.21	19.2	1.42	0.93	5.90	66.4	7.45	66.4	6.02
D15	0.76	0.28	..	4.50	17.2	1.17	0.60	9.90	64.9	8.62	64.9	7.22

Table 2—Influence of the Temperature of Hardening

Steel	Average Analysis								Hardening Temperature, ° C.	Rockwell Hardness	Cutting Time, Min.
	C	Si	Mn	Co	W	V	Mo	Co			
4 Steels	0.74	0.20	0.32	4.08	17.9	0.83	..	..	1250	64.7	2.27
D5, 6, 16, 17	..	..	..	..	..	..	..	..	1275	65.6	3.05
	..	..	..	..	..	..	..	..	1300	65.8	3.55
	..	..	..	..	..	..	..	..	1325	65.5	3.14
D9	0.69	0.27	0.35	4.37	13.2	1.56	..	..	1250	64.5	2.58
	..	..	..	..	..	..	..	..	1275	65.1	4.75
	..	..	..	..	..	..	..	..	1300	65.6	3.82
4 Steels	0.71	0.23	0.28	4.38	18.3	1.50	..	..	1250	64.1	3.37
D11, 18, 19, 20	..	..	..	..	..	..	..	..	1275	64.6	4.25
	..	..	..	..	..	..	..	..	1300	65.0	5.24
	..	..	..	..	..	..	..	..	1325	64.9	4.02
3 Steels	0.79	0.26	..	4.86	18.0	1.21	0.78	5.60	1250	65.2	4.24
D12, 13, 14	..	..	..	..	..	..	..	..	1275	65.9	5.15
	..	..	..	..	..	..	..	..	1300	66.0	7.11
	..	..	..	..	..	..	..	..	1325	65.8	5.67
D15	0.76	0.28	..	4.50	17.2	1.17	0.60	9.90	1250	64.5	4.27
	..	..	..	..	..	..	..	..	1275	65.3	5.67
	..	..	..	..	..	..	..	..	1300	64.9	8.63
	..	..	..	..	..	..	..	..	1325	64.7	8.92

Table 3—Influence of the Drawing Temperature

Steel	C	Si	Mn	Cr	W	V	Mo	Co	Drawing Temperature, ° C.	Rockwell Hardness	Cutting Time, Min.
D16	0.70	0.27	0.17	4.38	17.4	0.86	..	..	560	63.0	2.67
	..	..	..	..	..	..	..	..	580	64.0	3.12
Hardened at 1290° C.									600	63.5	3.60
	..	..	..	..	..	..	..	..	620	63.1	3.02
	..	..	..	..	..	..	..	..	640	62.4	2.54
D11	0.73	0.28	0.34	4.46	18.0	1.52	..	..	560	63.5	3.70
	..	..	..	..	..	..	..	..	580	65.0	3.74
	..	..	..	..	..	..	..	..	600	64.8	5.10
Hardened at 1300° C.									620	63.6	3.88
	..	..	..	..	..	..	..	..	640	62.1	2.97
D13	0.72	0.30	..	4.56	17.6	1.12	0.44	4.80	560	65.3	5.66
	..	..	..	..	..	..	..	..	580	65.8	5.66
	..	..	..	..	..	..	..	..	600	65.3	7.55
Hardened at 1310° C.									620	64.6	9.22
	..	..	..	..	..	..	..	..	640	63.0	5.14
D15	0.76	0.28	..	4.50	17.2	1.17	0.60	9.90	560	65.8	7.90
	..	..	..	..	..	..	..	..	580	65.7	10.11
Hardened at 1320° C.									600	64.8	9.53
	..	..	..	..	..	..	..	..	620	64.2	12.88
	..	..	..	..	..	..	..	..	640	63.1	9.30

CORROSION, EROSION AND PROTECTION OF METALS AND ALLOYS

Protection of Aluminum and Light Alloys from Corrosion in Sea Water by Cadmium Plating. (Protection de l'aluminium et des alliages legers contre la corrosion a l'eau de mer par depots electrolytiques de cadmium.) J. COURNOT. *Revue de Metallurgie*, July, 1929, pages 374–376.

Preliminary work indicated that a better protection is given by pure Cd than by its alloys. Different plating baths were tried. Cd sulphate bath was always giving spongy and crystalline deposits. Cd chloride bath was slightly better. Best results were obtained with: $CdCO_3$ 11.6 g., KCN 35 g., sodium phosphate 5 g., $K_4Fe(CN)_6$ 7.5 g., gelatin 2.5 g., water to make one liter. Excellent results were produced by using 0.5–0.7 amp./dc.^{2} Cd plated specimens were plated in a bath: CrO_3 (free from H_2SO_4) 250 g., chromium sulphate 4 g., $NaCO_3$ (crystalline) 14 g., boric acid 3 g. With 13–17 amp./dc.^{2} at 4–5 volts and exactly at 50° excellent adherence was obtained. Laboratory corrosion tests were very satisfactory. JDG

Protection of Light and Extra Light Alloys against Corrosion in Sea Water by Electroplating. (Recherches sur la protection des metaux et alliages legers et ultra-legers contre la corrosion a l'eau de mer par recovrements electrolytiques.) JEAN COURNOT AND JEAN BARY. *Revue de Metallurgie*, June, 1929, pages 312–318.

A study of the plating practice and protection afforded by plating to aluminum and duralumin. Preliminary flashing with Cu is helpful. Care must be taken to clean well and to protect from oxidation. Articles are sand blasted, washed in water, dipped for 5 seconds in HNO_3(18° Be.), thoroughly washed in water and rapidly immersed in Cu bath. The optimum depth of deposit is .007 mm. or about 600 mg./dc.^{2}. Both acid and cyanide baths can be used. Recommended:

$Cu(CN)_2$	(1)	22.5 g.	H_2SO_4	(2)	100 g.
NaCN		30.0	H_2O		1000 cc.
$NaCO_3$		10.0	$CuSO_4$		Saturated at
H_2O		1000 cc.			20° C.

For (1) use 0.6 amp./dc.^{2} and 2–3 volts. For (2) use 1.0 amp./dc.^{2} and 2–3 volts. Cobalt can be plated directly on Al and duralumin provided extra care is exercised in cleaning. Better results are obtained in Cu flash. Bath recommended: double cobalt ammonium sulphate 175 g., water 1000 cc. Plate at 15° using 1–2 amp./dc.^{2} Cadmium can be plated directly on Al and duralumin with better results than on Cu flash. Several formulae are given. The authors prefer: $Cd(CO_3)_2$ 12 g., KCN 35 g., H_2O 1000 cc. Plate at 15° using 0.5–1.0 amp./dc.^{2} and Cd anodes. Chromium plating requires insoluble (lead) anodes. Specimens are Cu flashed and well washed. Three formulae are given. Recommended precipitate 200 g. chrome alum with NH_3. Wash the hydroxide and dissolve in 120 g. chromic acid dissolved in 2000 cc. H_2O. By using 10 amp./dc.^{2} at 40–45° for 45 minutes 0.007 mm. deposit is produced. Nickel plating was touched only superficially on account of large amount of work already published. Plate on flash in a bath: double nickel ammonium sulphate 75 g., magnesium sulphate 15 g., boric acid 15 g., water 1000 cc. Use 0.3 amp./dc.^{2} at 20° for about 30 minutes. Deposits are usually porous. Plating on Mg is difficult because Mg decomposes even distilled water. After sandblasting the articles are directly immersed with the current on in the bath: $Cu_2(OH)_2CO_3$ 27.6 g., NaCN 54 g., $NaCO_3$ 2.6 g., water 1000 cc. Use 3–4 amp./dc.^{2} at the beginning. After 5 minutes rinse and place in acid Cu bath. The addition of 2 g. hyposulphite to the first bath brightens the deposit. Adherence is very good, but the grains of sand imbedded in blasting destroy the uniformity of the coating. A series of tests was conducted on plated bars to check the adherence. In every case plating was satisfactory in this respect. Immersion in the artificial sea water showed the protecting power to be (increasing) Co-Cd-Ni-Cr. JDG

Contribution to the Question of the Passivity of Metals. (Zur Passivitätsfrage der Metalle.) I. N. STRANSKI AND Z. O. MUTAFTSCHIEW. *Zeitschrift für Elektrochemie und angewandte physikalische Chemie*, July, 1929, pages 393–395.

This paper discusses a new possibility of explaining the passivity phenomena. From recent theoretical results on the growth and dissolution of crystals it can be concluded that it is sufficient for the retardation of the dissolution of a crystal if the separation of only a few constituent particles on the surface compared with the total number of this face is made difficult, i. e., particles on the crystal corners and edges. HA

Testing of the Corrosion Stability of Alclad. (Prüfung der Korrosionsbeständigkeit von Alclad.) E. RACKWITZ AND E. K. O. SCHMIDT. *Korrosion und Metallschutz*, June, 1929, pages 130–141.

Corrosion tests on a large scale with alclad (duralumin coated with pure Al) in comparison with pure Al and duralumin. See critical abstract in this issue page 235. EF

Cementation of Light and Extra Light Metals as a Means of Protection from Corrosion in Sea Water. (Cementation des alliages legers et ultra-legers en vue de leur protection contre la corrosion a l'eau de mer.) JEAN COURNOT AND EUGENE PEROT. *Revue de Metallurgie*, June, 1929, pages 318–325; July, 1929, pages 367–374.

Cementation of Al and duralumin was attempted by heating the specimens in powdered metals and by heating electrolytically coated samples. Powdered metal method giving promising results was studied to completion. Copper deposit heated in almost neutral atmosphere under eutectic point, 540°, slightly scales and does not alloy with the base. Above 540° alloys rapidly. With a short heating a practically neutral atmosphere is sufficient to prevent excessive scaling, with longer heating the use of immersion in fine sand is recommended. Nitrate mixtures gave poor results. Cemented surfaces become covered with ripples proportional in number to the thickness of the coating. With 0.2–0.3 mm. of it they disappear. Penetration in alloying is much faster for duralumin than for Al. Quenching from cementation temperature permitted raising the hardness from 32.5 Brinell (at 540°) to 92 Brinell (using 615° cementation and quench). At higher temperatures the hardness dropped again. The penetration of Cu depends on the thickness of its coating. No improvement in resistance to artificial sea water was found. The density of the current for Cu plating before casing had no effect. Heating of Cu plated articles in a mixture of $NaNO_2$ and KMO_3 gave better casing, but the presence of the salt in the outer layers renders the metal unfit for use. Casing of Al in powdered ferro-chrome of different carbon contents was impossible at 600°. A definite action takes place here with duralumin—a eutectic compound precipitates all over the specimen and intercrystalline cohesion is destroyed. The precipitate is similar to Al_2Cu. Larger C content reduces the cementing power of ferro-chrome. Specimens coated with Cu were plated with Ni, Cd, Cr and Co. After heating, the surface almost always was deformed and covered with wrinkles to the extent proportional to the temperature used. The amount of penetration depended on the thickness of Cu layer. A solid solution, a compound at the grain boundaries resembling Al_2Cu and proportional in amount to the thickness of Cu layer, and a third constituent found as isolated crystals or needles were observed. Two latter contain presumably the metal of the outside coating. They are very hard. Crystals are unattacked by NaOH, HF and HCl. The needles are easily attacked by them. Cu plating of 94–6 Mg-Al alloy can be done but with indifferent results. The coating is not tight enough to prevent oxidation. JDG

A Method for Rapid Determination of Permeability and Adhesion of Varnishes Used for Preservation of Light Alloys. (Methode permettantune appreciation rapide de la permeabilite et d'adherence des vernis employes a la protection des alliages legers.) AUBERT AND G. DIXMIER, 2ND. *Revue de Metallurgie*, June, 1929, pages 307–308.

A method for testing the penetrability of varnishes applied to light metals is proposed. Cylinders one cm. diameter used as specimens. They are inserted in liquids as cathodes and are completely surrounded by anodes. Different voltages were applied and the currents measured. As the end point 0.05 amp. was used. Voltage varied from 0.5 to 2.0 volts. The speed of failure was directly proportional to the pressure. Two volts were selected as standards for testing. The time for failure varied from 2 minutes (a nitrocellulose lacquer) to 100 hours (boiled linseed oil). Varnishes with tar of linseed oil base were superior to nitrocellulose or artificial gum laquers. JDG

Protection of Aluminum by Deposits Formed on It in Salt Solutions. (Protection de l'aluminium par depots effectues dans des solutions Salines.) Abstracted by R. CAZAUD. *Revue de Metallurgie*, June, 1929, pages 309–310.

Properly cleaned strips of Al were immersed in different salt solutions for different lengths of time (usually minutes). The results of attack are tabulated. Salt deposits do not prevent corrosion at all. Water under pressure protects poorly. Metallic oxides in alkaline solutions form well protecting adherent deposits. The quality of the finish does not have a pronounced effect on resistance to corrosion. JDG

Intercrystalline Corrosion of Duraluminum. Frank M. Bonder. *Aviation*, June 15, 1929, pages XCIX–XCX.

The effect of corroding materials on Duraluminum is a double one: a roughened or pitted surface (common form) and an intercrystalline corrosion. Usually one or the other predominates. Replacing silicon by copper, wrought alloys are more susceptible to intercrystalline corrosion but less for the common form. The rapidity of corrosion depends on the composition of the alloy, on its heat treatment, and the percentage of its impurities. Chemically pure aluminum shows the greatest resistance to corrosion, which is decreased by the commonly used elements: copper, manganese, magnesium and silicon. Besides these principal elements other additions are applied in the "overloaded duraluminum" promoting still more the intercrystalline corrosion, especially iron, chromium and nickel. Concerning the method of quenching, cold water quenching results in a much less susceptibility to intercrystalline corrosion than oil or hot water quenching without affecting the mechanical properties (Bureau of Standards). Since the impurities can be entirely eliminated, this source of intercrystalline corrosion can be disregarded. Naturally both forms of corrosion largely depend on the corroding media; especially the chlorides proved to be most active. According to the theory of Williams and Homerberg, intercrystalline corrosion in duraluminum progresses in the same manner as in steel or brass. Both investigators believe in an intensifying effect by stress, promoting a rapid absorption of the corroding media at the grain boundaries, and a progress into the part along the grain boundaries under decomposition of the metallic compounds. The tensile properties are more or less affected by the intercrystalline corrosion, depending on the intensity of the attack. There is a localization of stresses at points where the cross section is reduced by corrosion or tool marks. Even scratches are not permitted, f. i., on aeroplane engine crankshafts. Finally the author discusses the most important methods used in protecting duraluminum against both kinds of corrosion: anoding oxidation process, using sodium silicate or warm chromic acid solution, cover of grease like lanolin or lard oil, immersing in a hot solution of chromium salt or potassium bichromate, cover of sodium silicate with a proper heat treatment, paint, varnish or enamel coating, rubbing the surface with a thin coating of oil, dusting the oil film with aluminum powder, periodic polish, Schoop metal spray process and finally the Alclad-process of the Aluminum Company of America. The results of a corrosion test is demonstrated by three pictures. EF

Oxidation of Iron and Steel by Heat. L. B. Pfeil. *Heat Treating and Forging*, June, 1929, pages 734–740; July, 1929, pages 852–859.

From paper before Iron and Steel Institute; May, 1929. Bibliography of 13 references. Experimental study of the formation of scale and of its characteristics. Scale is normally smooth, compact, and free from cracks and fissures in spite of the oxidation involving an expansion of the order of 100%. It consists normally of three distinct layers, differing in appearance, structure and composition. With a few exceptions, non-ferrous elements present in iron before the oxidation are concentrated in the innermost layer. Foreign substances placed on the surface of the iron are not forced away by the formation of scale but remain unmoved and become enveloped in the scale. When oxidation is slow the formation of large scale crystals exhibiting plain crystal faces occurs, the scale surface sometimes showing high relief. The commonly accepted hypothesis that the outside of the scale was formed first, further oxidation having displaced it bodily outward, is not consistent with these facts. The facts indicate that the outer part of the scale is the last to form, the middle portion being the first. The only mechanism of oxidation consistent with the facts is that of counter-current diffusion, the iron diffusing outward and the oxygen inward through the scale. It is not of essential importance whether the iron diffuses as iron atoms or in some other form. Scale is normally unsaturated with iron, and metallic iron will join such scale if the two are heated in contact. MS

Determination of Tin Plate. (Die Bestimung der Zinn Auflage auf Weissblechen.) Dr. F. Peter. *Chemiker Zeitung*, June 5, 1929, pages 438–439.

Previous determinations which are mostly gravimetric are anticipated. The author proposes the following method: cleaning of a 100 × 200 mm. piece, weighing, dipping into boiling hydrochloric acid (spec. grav. 1.08), loss of weight is equal to tin and iron passing into solution, determination of iron content in the solution, after correcting the value of 0.4 percent due to impurities in mild steel, balance is tin. Time required for analyses: about 20 mins. A table of some analyses proves the accuracy of this new method. EF

Corrosion of Light and Extra Light Metals and Alloys. (La Corrosion des metaux et alliages legers et ultra-legers.) The work of the Sub-Committee on light and extra light alloys. Fourth part. A Bibliography of 61 names. Abstracted by R. Cazaud. *Revue de Metallurgie*, July, 1929, pages 367–377.

The general title of a series of papers abstracted under their proper titles. JDG

Modern Trend in Fighting Corrosion. T. Henry Turner. *Heat Treating and Forging*, July, 1929, pages 860–864.

From a lecture before the Sheffield Metallurgical Association outlining the methods of preventing corrosion of metals. Methods may be grouped into two major groupings; (1) surface protection of readily corrodible metals and alloys, and (2) resistant alloys. In addition to corrosion of finished articles, great loss of metal occurs in production operations, such as scaling of steel during soaking, forging, rolling and annealing. Much of this can be reduced by preventing the steel from coming in contact with the atmosphere. Outstanding successes so far achieved in the fight against corrosion are: (1) development of thick deposits of nickel, with possibly composite layers of copper and chromium in electroplating; (2) production of martensitic and austenitic stainless and super-stainless steels in ferrous metallurgy; (3) replacement of brass by cupro-nickel and Monel metal in non-ferrous metallurgy; and (4) the introduction of manganese-nickel and chromium-nickel alloys and heat-resistant steels for high temperatures. MS

Protection of Light Alloys with Tars. (Étude de la protection des alliages legers par les goudrons.) Aubert and A. Pignot. *Revue de Metallurgie*, June, 1929, pages 310–312.

A series of paints composed of coal tar residues in combination with different solvents and applied to aluminum alloys were tested for drying qualities, resistance to sea water, effect of heating and the solubility in a mixture of gasoline with lubricating oil. JDG

The Parker Process. (Der Parker Prozess.) E. Liebreich. *Metallwirtschaft*, May 31, 1929, pages 526–527.

The Parker Process consisting of a treatment of iron by H_3PO_4 and thus coating it with a protecting layer, is compared with other standard coating and protecting treatments of Fe in some tests of the author. The results obtained in twelve different media as air, some waters, steam, ammonia, various acids, etc., are clearly arranged in a table, proving a great resistance to corrosion due to the salt character of the coating which prohibits galvanic currents. The cheap and easy performance of the process without electric energy and elevated temperatures, the small change of dimensions (0.005–0.007 mm.), the excellent surface appearance, the favorable base for lacquers are mentioned as well as the present industrial applications. EF

Increased Corrosion Resistance of Duralumin. (Erhöhte Korrosionsfestigkeit von Duralumin.) *Metallwirtschaft*, June 14, 1929, pages 586–587.

Referring to review dealing with the publications of the Bureau of Standards concerning the corrosion stability of Alclad, it is pointed out that the effective section under stress is reduced by say, 10 percent due to the protecting layer. In order to avoid, this dead weight without at the same time reducing the resistance to corrosion, a coating of a duralumin alloy K50 called Duralplat is applied. This can be age hardened. EF

On the Theory of Passivity V. On the Influence of Surface Films upon the Potential of a Metal. (Zur Theorie der Passivitätserscheinungen V. Ueber den Einfluss von Deckschichten auf das Potential eines Metalles.) W. J. Muller. *Monatshefte für Chemie*, June, 1929, pages 53–58.

After referring to his previous investigations, the author discusses the influence of a surface film upon the potential of base metals, that is to say, a metal which has self-potential. Haber noticed that a nonconductor immersed into a solution shows the potential of the solution and a potential difference film-metal which produces a local current in the short-circuited element metal-electrolyte-film must occur in case of metals covered by a film. The magnitude of this local current results from Ohm's law: $i = \frac{e}{w_1 + w_2}$, where e = EMF of the element metal-electrolyte-film, w_1 = resistance in the pores and w_2 = resistance of the surface layer. Local current multiplied by resistance in the pores is an apparent potential which must be subtracted from the potential of the metal in order to obtain the electrometrically determined potential which is called the correction coefficient, the magnitude of which is $A = \frac{Fn^1}{Fn^1 + (Fo - F)n}$ wherein F = covered area, $Fo - F$ area of pores n^1 = specific conductivity of the electrolyte in the pores and n = spec. conductivity of the film. The values of the correction coefficient have been computed for different stages of covering and for various conductivities of film and electrolyte. A comparison with previously investigated potential values of covered aluminum electrodes exhibited plausible values for the condition of film which are in agreement with other publications. EF

STRUCTURE OF METALS AND ALLOYS

Metallography and Macrography

Microstructure of Rapidly Cooled Steel. J. M. Robertson. *Heat Treating and Forging*, July, 1929, pages 865–872. From paper before Iron and Steel Institute, May, 1929. See Metals & Alloys, July, 1929, page 25. MS

The Saturation Limit of the α(Cu Sn)-Solid Solution. (Ueber die Sattigungsgrenze des α(Cu Sn)-Mischkristalls.) M. Hansen. *Mitteilungen der deutschen Materialprufüngsasutalten*, Sonderheft V, 1929, pages 23–25.

The results of an investigation on the saturation limit and solubility limit of Cu-Sn-alloys between 400 and 800° C. are discussed and illustrated by micro-photographs. Ha

The Ac_1 Range of Carbon Steel and Related Phenomena. Axel Hultgren. *Transactions American Society for Steel Treating*, August, 1929, pages 227–256.

Previous investigators have shown by other methods that the transformation of pearlite into austenite on heating requires a temperature range for its completion. The present author has shown the progress of this transformation by quenching specimens of identical composition after one hour period of heating at various temperatures in the critical region. Three factors are stated to cause this transformation to occur in a range, viz., (*a*) presence of alloy elements, (*b*) heterogeneity due to segregation on solidification, (*c*) slow diffusion of carbon and possibly of other elements. It is concluded that (1) the Ac_1 transformation of a given steel at constant temperature within Ac_{reg} proceeds faster in the unannealed than in the annealed condition. (2) In annealed bars the transformation occurs faster, the more advanced the stage of reduction in hot working. (3) The degree of transformation obtained after one hour appears not to be far below an asymptotic value for the temperature in question. Thus one hour may be considered sufficient as a heating period in tests for comparative purposes. A number of phenomena are mentioned which are believed to be affected by the slow rate of diffusion of carbon and other elements. ESC

On the Double Diagram of the Iron–Carbon System. Dr. Kotaro Honda. *Transactions American Society for Steel Treating*, August, 1929, pages 183–190.

Includes discussion. Paper presented before the Western Metal Congress, Los Angeles, California, January 14 to 18, 1929. The double diagram of the iron-carbon system is widely used in Europe and America, especially in Germany where it was born. Experimental evidence renders the direct precipitation very doubtful, further X-ray analysis does not accord with the consequences of the double diagram. Other evidence is adduced to demonstrate the conclusion that for the pure iron–carbon system, the single diagram is the simplest and most satisfactory one. ESC

On the Distribution of Austenite in Specimens of Quenched Carbon Steels. K. Honda and A. Osawa. *Science Reports Tohoku Imperial University*, May, 1928, pages 47–58.

Several Swedish steels containing 0.3%, 0.6%, 0.9%, 1.5% and 1.7% carbon were quenched in water from different temperatures between 800 and 1190° C. To study the distribution of austenite, X-ray, microscopic and hardness examinations show that the amount of retained austenite decreases from the outer to the inner parts of the quenched samples. The influence of the quenching temperature and the carbon content was also studied. Results are given in the table.

Carbon Content	Quenching Temperature Deg. C.	Retained Austenite X-Ray Analysis Near Surface	Retained Austenite X-Ray Analysis Inner Part	Shore Hardness Near Surface	Shore Hardness Inner Part
1.7%	1190	36	19	60	71
1.7	1150	21	17	69	71
1.5	1100	13	8	65	70
0.9	1180	26	20	69	73
0.9	1070	22	15	72	80
0.9	900	20	15	74	65
0.9	800	12	5	72	63

GN

On the Equilibrium Diagram of the Iron–Molybdenum System. T. Takei and T. Murakami. *Science Reports Tohoku Imperial University*, May, 1929, pages 135–153.

The equilibrium system of iron–molybdenum was obtained by microscopic, electric resistance, dilatometric and magnetic examinations. According to the authors there exist six solid solutions. To a content of about 45 percent molybdenum the new system is in agreement with that of W. P. Sykes. Above this the authors' system is far different from those known heretofore. Two intermetallic compounds Fe_2Mo_2 and FeMo could be found. Solubility of Mo in Fe 38% at 1440° C., 6% at room temperature. The A_3 transformation raised molybdenum. GN

Structure and X-Ray Analysis

Investigations of Structure in Cast Metals and Alloys. (Gefügeuntersuchungen an gegossenen Metallen und Legierungen.) E. Schmid. *Metallwirtschaft*, July 5, 1929, pages 651–654.

Influence of structure in cast metals and alloys on some physical and technical properties is given. Grain boundaries are weak spots on account of low heat strength. Ruptures of wires on rolling mills furthered along crystal boundaries is referred to. Besides this "geometrical" effect, the radial edge zone has a considerable crystallographic significance for the further forming operations of ingots due to anisotropies of crystals. Data of such different properties along different crystallographic axes are presented in tabular form. A zinc rod with radially arranged rod crystals would possess a modulus of elasticity of 11,376,000, and a coefficient of expansion of about 38×10^{-6}. But if this rod would be built up by fibrous crystals parallel to the longitudinal axis, these values would change to 17,064,000 and 14×10^{-6}, respectively. The importance of the crystal texture is obvious. The author succeeded in producing different grain structures, removed some fibrous crystals and made X-ray photographs, some of which are reproduced in the present paper. The results of the evolution of the examined metals and alloys belonging to five different crystallographic systems are summarized in a table showing the position of crystallographic axes in regard to the longitudinal axis of these coarse fibrous crystals. To state an example: all cubic metals proved that there is always one side of the cube parallel to the longitudinal direction of the fibrous large crystals. The investigations were on two eutectic alloys: Al-Si and Cd-Zn. In conclusion the eventual cause of this development of radiant fibrous crystal zones at the rim is pointed out and set in parallel with tests of crystal growth in tubes: "a natural selection" takes place preferring the longitudinal direction of the fibrous crystals as a direction of maximum velocity of grain growth. EF

Determination of the Particle Size by X-Rays. (Ueber roentgenographische Teilchengrössenbestimmung.) R. Brill. *Metallwirtschaft*, July 19, 1929, pages 699–701.

Little work has been done on the subject of the application of X-rays to the determination of the particle size. A metal or alloy is not exclusively defined by its components, composition and crystal structure, but also by the size of its crystals. Single crystals have other properties than finely crystallizing matter. Technical importance of strength, due to decrease of size of crystals is referred to. Grain size of some steels cannot be developed under the microscope, the application of which is limited by the wavelength of light. Short waves of X-rays are suitable. Location and intensity of interference—aside from the monochromatic X-rays—are functions of the regular arrangement of the atoms, it is true, but the sharpness, the more or less vagueness of the reflection lines, depends on the size of the crystallites. The same effect occurs with defraction gratings. Both methods for comparing the size of crystallites with the width of reflection lines—which are also influenced, by the absorbing power of matter—the Scherrer and the Laue method are discussed. Calculations on a large scale with the same material furnish excellent results. A practical example illustrated by a diagram explains how to determine the content of particles of iron coming from decomposed iron carbonyl, amounting to four billions of single crystals. EF

The Structure of Silver-Aluminum Alloys High in Aluminum. (Der Aufbau der aluminum reichen Silber-Aluminiumlegierung.) M. Hansen. *Mitteilungen der deutschen Materialprüfungsanstalten*, Sonderheft V, 1929, pages 29–38.

The equilibrium diagram of silver-aluminum alloys with 0 to 60% Ag the liquidus curve and the eutectic temperature were determined and the solidus curves as also the solubility of silver in aluminum microscopically determined. The solubility of silver increases from 0.75% Ag at 200° to about 48% Ag at the eutectic temperature of 558° C. Below 200° the solubility decreases still more. Numerous tables and micro-photographs illustrate the article. Ha

On the Lattice-Constant of Quenched Carbon Steels. S. Sekito. *Science Reports of Tohoku Imperial University*, May, 1929, pages 69–77.

Six steels with carbon contents of 0.396%, 0.73%, 1.42%, 0.82%, 1.02%, 1.21% were quenched from 780,840 and 1070° C. in water. X-ray photographs show that the axial ratio of the tetragonal lattice diminishes to the center of the quenched specimens. The axial ratio is influenced by the cooling velocity in quenching and by the carbon content. Annealing immediately forms the body-centered cubic lattice. GN

PHYSICAL, MECHANICAL AND MAGNETIC TESTING

Magnetic Alloys of Iron, Nickel and Cobalt. G. W. ELMEN. *Journal of Franklin Institute*, May, 1929, pages 583–617.

Magnetic properties of alloys composed of the ferro-magnetic metals, iron, nickel and cobalt, have been systematically investigated in the Bell Telephone Laboratories since 1913. The compositions of the alloys which have been tried are graphically shown by an equilateral composition triangle proving that the survey covers fairly completely the whole field of composition. The preparing of the alloys is described and particular attention is called to heat-treatment which greatly influences the magnetic properties. The following three kinds of heat-treatment were applied: (*a*) "annealed" at 900–1000° C. for an hour, (*b*) "air quenched" that is to say reheated to 600° C. and rapidly cooled, (*c*) "baked" which means held for a long time at 425° C. Magnetization curves were plotted from the measurements, and induction was also determined. The permeabilities computed from the induction measurements were plotted either against the flux density or the magnetizing force. Two methods are used for determining the hysteresis loss. The abundant results of the multitudinous investigations are plotted in the form of seven solid diagrams (using the composition triangle as a base) showing the material changes with composition and heat-treatment. Stress has been laid upon the group of alloys of high permeability and low magnetic forces in the Fe-Ni series, called permalloys, as well as upon the ternary alloys of constant permeability and extremely low hysteresis loss at low flux densities, called perminvars. The effects of adding non-magnetic elements as Cu, Cr, Mo, Wo and Ta have been studied. A few of the principal uses of the produced alloys are described. EF

Crystal Structure and Ferromagnetism. (Kristallstruktur und Ferromagnetism.) W. SCHMIDT. *Physikalische Zeitschrift*, May 1, 1929, pages 259–261.

The temperatures in degree abs. at which changes in physical properties occur are in agreement with the following equation: $T = T_s/m\,n$ wherein; $m = 14$, $n =$ whole number between 1 and 13, $T_s =$ melting temperature. The same law is extended to tin with respect to the known allotropic changes. EF

Determination of Inner Stresses in Rods and Tubes. (Der Nachweis innerer Spanungen in Stangen und Röhren.) G. SACHS. *Mitteilungen der Deutschen Materialprüfunganstalten*, Sonderheft V, 1929, pages 138–144.

Every non-uniform shape change in a material leaves internal stresses. By removing parts of the material these stresses become active and elastic deformations take place which can be measured and permit calculating the stresses. The paper shows how the calculations are carried out and how the distribution of stresses can be determined therefrom. HA

Tension-Compression-Tests on Brass Crystals (Bauschinger-effect). (Zug-Druckversuch an Messingkirstallen (Bauschinger-effekt).) G. SACHS AND H. SHOJI. *Mitteilungen der deutschen Materialprüfungsanstalten*, Sonderheft V, 1929, pages 113–122.

Describes a series of tests and the production of brass crystals. It is not quite possible to explain certain irregularities in the behavior under tension and compression. HA

Dependence of the Elastic Elongation Number of Copper on the Treatment and Testing. (Abhänggkeit der elastischen Dehungszahl des Kupfers von der Vorbehandlung und Versuchsführung.) W. KUNTZE. *Mitteilungen der deutschen Materialprüfungsanstalten*, Sonderheft V, 1929, pages 97–113.

This comprehensive investigation was undertaken to check the elasticity figures especially for non-ferrous metals. According to the treatment of copper both the Hook's law and hysteresis are observed. The coefficient was determined for different working of the copper. HA

Fatigue Testing of Sheet Metals. J. R. TOWNSEND AND C. H. GREENWALL. *Metal Stampings*, Aug., 1929, pages 599–600.

Abstract of paper presented before American Society for Testing Materials. Describes test machine developed and testing procedure. Materials investigated consisted of five alloys of alpha brass, and one each of nickel-silver, phosphor-bronze and Everdur. Photomicrographs indicated that fatigue failure of these metals is transcrystalline. The results show that the ratio of endurance limit to tensile strength varies from 0.14 to 0.36 whereas for steels it ranges from 0.35 to 0.67, averaging about 0.40. Cold work raises the endurance limit but not proportionately to the increase in tensile strength produced by the same means. Material hardened by cold work shows a progressive decrease in ratio of endurance limit to tensile strength. MS

ELECTRO-CHEMISTRY

Electroplating

Conditions of Formation and Properties of Extremely Thin Electrolytic Deposits of Nickel. (Bildungsbedingungen und Eigenschaften dünster elektrolytischer Nickelschichten.) K. M. OESTERLE. *Zeitschrift für Elektrochemie und angewandte physikalische Chemie*, Aug., 1929, pages 505–519.

The purpose of this thorough investigation was to determine the influence conditions, which are inherently connected with the deposition of metal, because they are the natural consequence of chemical properties of the material and the conditions of reaction, have on the electrolytic deposit of metals. The test methods are described in detail and the results given in diagrams. HA

Industrial Cleaning of Metals. A. K. GRAHAM. *Metal Cleaning & Finishing*, July, 1929, pages 245–246.

Abstract of paper read before the American Electroplaters' Society at Detroit. Methods of cleaning may be classified as follows: (1) removal of grease by means of chemical cleaners or organic solvents; (2) removal of oxide by means of pickle baths of dilute solutions of HCl or H_2SO_4; (3) cleaning prior to enameling, lacquering, painting, etc.; (4) before hot dipping; (5) prior to producing chemical coloration; and (6) for electroplating. Cleaning operations in the last four cases usually involve a combination of the first two. Electrolytic cleaning is finding favor. An efficient means of carrying out this method is to first make the work the cathodein a dilute acid or alkaline solution and then to make it the anode in another tank. Pickle controls are beneficial as they retard surface attack, lessen fumes from the bath and reduce acid consumption. MS

Preparation of Articles for Chromium Plating. WALTER L. PINNER. *Metal Cleaning & Finishing*, July, 1929, pages 249–252.

Discusses particularly case where nickel plating on steel precedes chromium plating. Since the intense, permanent luster of chromium magnifie even slight defects, particular care must be taken in all cleaning, grinding and polishing operations. Discusses the influence of these processes on the chromium plate. Nickel plate should possess desired luster and adhere sufficiently to the base metal so as not to peel immediately upon chromium plating. It should also possess sufficient corrosion resistance in itself. Nickel peeling is probably due to hydrogen evolution rather than strain in the chromium deposit. About 90% of this trouble is due to improper cleaning of the steel for nickel plating. Cites rules for proper cleaning. MS

What We Do Know about Chromium Plating. CHARLES H. PROCTOR. *Metal Cleaning & Finishing*, July, 1929, pages 271–274, 302.

First part of a serial. Outlines various items of equipment needed for a chromium plating plant. For plating solutions the following formula can be used for plating on all metals of the commercial type: water, 1 gal., CrO_3, 33 oz., natural iron chromate, 1 oz. (fine powder); H_2SO_4, 60 deg. Bé., 1/3 oz. (liquid measure); temperature, 80–90 deg. F. When operating solutions continuously the following may be used: water, 1 gal., CrO_3 48 oz., natural iron chromate, $1\frac{1}{2}$ oz., H_2SO_4, 1/3 oz. Recommends natural iron chromate as an addition agent, as the baths have greater throwing power, require lower current densities and lower operating temperatures. Gives formulae for baths containing no iron and discusses means of controlling sulphate content. MS

Progress in Zinc Electrolysis with Particular Regard to the Tainton Process. (Ueber Fortschritte auf dem Gebiete der Zinkelektrolyse unter besonderer Berücksichtigung des Tainton Verfahrens.) DR. G. EGER. *Metall und Erz*, August 1, 1929, pages 373–383.

The paper presented at the Gesellschaft Deutscher Metallhütten und Bergleute May 31, 1929, outlines the development of the zinc sulphate electrolysis according to the conventional processes. Some of the more important bases of the process, especially with regard to the influences due to varying contents of acid in the bath on one hand and the variable current densities during electrolysis on the other hand, are given. The main characteristic features of the Tainton Process: strongly acid solutions and high current densities during electrolysis. Description of the operation on a large scale at Kellogg, Idaho. The present practice of the Tainton process. Reference to some of the more important economical viewpoints. Paper includes discussion. EF

INDUSTRIAL USES AND APPLICATIONS

Metals and Alloys for Industrial Applications Requiring Extreme Stability. JEROME STRAUSS. *Transactions American Society for Steel Treating*, August, 1929, pages 191–226.

"Bibiliography" of 23 references. Paper presented before the Western Metal Congress held in Los Angeles. This paper records the uses of the most widely applied metals and alloys under conditions demanding permanence, either superficial or otherwise, usually when exposed to the active destructive agents in some form, corrosion, erosion and (chiefly) elevated temperatures. These three agencies are discussed in detail including the relationship of laboratory or semi-practical test data to the results obtained in actual practice, as well as the influence of the manner of application upon the performance of a metallic material. The various alloys are described, grouped according to the elements present in their composition in major proportion. The copper group, including the commercially pure metal, brasses, true bronzes, manganese bronzes, aluminum bronzes, nickel silvers and others, find wide application for exposure to atmosphere, sea water and natural waters. Pure aluminum and selected aluminum alloys have recently become of some importance in the chemical industries and for shipboard use. The pure metals, tin, zinc, lead and their alloys, are also discussed. Cast iron and simple carbon steel of structural grades still hold first position in respect to quantity consumed. But none of these materials is especially advantageous when exposed to very high temperatures, either alone or combined with chemical attack. For such service much use has been made in late years of nickel alloys and of the highly alloyed special steels. ESC

Metals Applied to Airplane Construction. HAROLD CRARY. *Heat Treating and Forging*, June, 1929, pages 709–711.

Aircraft manufacturers require of the metals used "maximum strength with minimum weight." Describes practice of the Boeing Airplane Company. Steel and aluminum alloys are heat-treated to make them hard and tough. Every steel part is cadmium plated after heat-treatment. MS

Metals Used in Airplane Making. GEORGE S. HERRICK. *Iron Age*, July 25, 1929, pages 211–214.

Majority of airplane builders are using chrome molybdenum steel tubing. British and Continental builders still use a medium carbon seamless steel tube. The Army and Navy specification for this tubing is listed as No. 57-180-1A, having an analysis of C—0.20 to 0.30 percent, Mn—0.50 to 0.80 percent, P—0.045 percent maximum and S—0.050 percent maximum. Chrome molybdenum steel tubing is known as specification No. 57-180-2A by the Army and Navy, and consisting of C—0.25 to 0.35 percent, Mn—0.40 to 0.60 percent P—0.04 percent maximum, S—0.045 percent maximum, Cr —0.80 to 1.10 percent, and Mo—0.15 to 0.25 percent. This is similar to S. A. E. specification No. 4130 x. Aluminum and its alloys are much used. Sizes and gages of sheets are usually 16 to 18 gage, corrugated. Sheets for tanks are of 14, 16, 18 or 20 gage, depending on the capacity of the tank. Miscellaneous fastenings and accessories must conform with Army and Navy specifications. In regard to corrosion no protective coating is required for aluminum. Alloy steels are coated to meet Army and Navy specifications. VSP

Metals in Airplane Construction. (Die Metalle im Aufbau des Flugzeuges). H. STEUDEL AND G. BOCK. *Zeitschrift für Metallkunde*, July, 1929, pages 213–223.

Metals are replacing wood and other materials more and more in airplane construction. Further progress will largely depend on improvements of light alloys. The essential stresses which are met in airplanes are clearly and fully outlined. A weight distribution in percent of a large modern plane is given. If an improvement in strength would allow a reduction of ten percent in the bearing parts, the paying load, which is now only 13 percent, could be increased by 30 percent. The importance of material is evident. The short second part of the paper deals with requirements which must be met from the viewpoint of economy, as low light weight percentage, low costs of production and attendance, and safety in flying. In addition to specific gravity the properties of material under static and dynamic stress, as elasticity, yield point, ultimate strength and elongation, capacity of work, modulus of elasticity, fatigue and damper strength, are of interest for the construction, while cold and hot shaping, working with chipping tools, welding properties and the kind of heat-treatment are of importance during manufacture. In a table the chief alloys and their principal properties are given and compared with two steels also used in airplane manufacture. Due to its low strength, pure Al (DIN 1712) is only applied in low stressed parts especially if welding is necessary. Otherwise Al-alloys are used. The new zinc-alloys, which possess still greater strength, are not used yet due to troubles of working. Mg-alloys attract attention due to their low specific gravity. The first steel (DIN 1661) is used for tubes and sheets for pipe-struts and junctions. The excellent weldability easily permits the construction of junctions. The second steel VCN $^{100}/_{12}$ is equivalent to the improved light alloys if the tensile strength is based on the specific gravity. A simple comparison is possible by means of two presented diagrams; elongation is plotted against tensile strength in the first diagram, and against $\frac{\text{tensile strength}}{\text{spec. gravity}}$ in the second one showing the superiority of light alloys. However, bending stress under axial compression must also be taken into consideration. The author develops the theoretical principles of this type of stress (two diagrams) and a great number of profiles are portrayed. The curves reveal that under conditions prevailing in aviation, light alloys are considerably superior to steel over the whole range of buckling length. In an exceptional case, if low air resistance is the primary requisite, steel is used because of its great modulus of elasticity and the possibility of small external dimensions. Question of local bending is discussed which can be overcome by avoiding of plain, smooth surfaces. Two typical English profiles are represented. Great ultimate elongation is desirable and demands along this line are fully met at the present. Ultimate elongation and strength are of decisive influence upon ability of absorbing energy which has been plotted in two diagrams against unit of volume and unit of weight. The light alloys are again more suitable for requirements in aircraft industry than steels. On the other hand, notch-toughness is very low in treated light metals it is true, but this property plays a subordinate role in airplane construction. Tests of alternating strength, which is much influenced by surface conditions, are in their infancy. The results of some tests are given showing again that light metals turn out favorably in comparison with steel. A method of testing airplane parts under conditions comparable with the actual is explained. This method of testing is mostly preferred at the present to determine fatigue properties. In regard to machining properties and hammering are of greatest importance, since pipes and sheets are widely employed. Capability of the above given Al-and Mg- alloys of being shaped hot is rather good. In case of artificially aged alloys, the initial conditions must be restored by a new heat-treatment. Mg-alloys have the advantage of automatic age-hardening. The excellent heat-forming properties are known in steels, which are applied in special cases. Two examples are illustrated. Apart from pure Al, cold working of light alloys is only possible to a lesser extent in comparison with steel of equal strength. Sheets, for instance, cannot be bent so sharply or pressed or embossed. In case of more extended shaping this must be followed by annealing. Lautal and similar age-hardened alloys exhibit a still smaller degree of cold working in spite of high ultimate elongation. The same can be stated for Elektron alloys. Radius of bending: 5–10 times of thickness of sheets in case of 0.5–2 mm. Greater shaping must be performed at 270°–330° C. Summarizing: that material is most satisfactory which requires the least heat-treatment. Steel STC 16.61 possesses excellent properties while more difficulties arise with steel VCN $^{100}/_{12}$. Welding is a very desirable property facilitating the erection. This is the reason why steel STC 16.61 is frequently applied in spite of its moderate strength. Two connections are illustrated. Annealing treatments after welding is discussed. Steel VCN $^{100}/_{12}$ practically cannot be welded in comparison with pure Al (fuel tanks). Improved alloys are only conditionally weldable; strength in around the weld joint is reduced by half or even more. In spite of its combustibility, Elektron can be welded very well by trained men. Duralumin, Lautal, harder Elektron metal and high quality steel are, therefore, mostly riveted or screwed. In respect to castings in aircraft construction, the author chiefly refers to a former paper (*Zeitschrift für Metallkunde*, **20**, 1928). Weight-saving requirements are met by Elektron. Alumin is applied in case of difficult castings, and KS Seewasser favorably resists corrosion. Steel castings are exceptions. Two examples of the new Junkers plane are shown. Mechanical machining, as cutting, filing, drilling, boring, etc., can easily be performed in all alloys with the exception of the VCN $^{100}/_{12}$ steel. Some experiences on corrosion tests on 8–9 year old airplanes are given. In conclusion other metals and alloys in airplane construction are briefly mentioned. EF

Translation

Negotiations are now under way which will assure the appearance of translations of articles appearing in foreign publications. Under this arrangement, the readers of METALS & ALLOYS *will be assured of receiving in English the best articles at almost the same time as they appear abroad instead of three months to one year later.*

The Solubility of Copper in Silver

By M. Hansen, Berlin-Dahlem, Germany

(*Translated by special arrangement from Zeitschrift für Metallkunde, June, 1929, pages 181–184.*)

The solubility of copper in silver has been determined by means of thermal and microscopic examinations by Osmond,[1] Friedrich and Leroux,[2] and von Lepkowski,[3] by means of measurements of the electric conductivity by Kurnakow, Puschin and Senkowski[4] and by Fraenkel and Schaller.[5,6] Fraenkel and Schaller[7] and Norbury[8] have proved by their refining tests that the solubility increases with increasing temperature. So far, however, no exact determination of the entire solubility curve has been available.[9]

Previous Investigations

Osmond found that "slowly" cooled alloys with 0.2 and 0.5% Cu were homogeneous, while an alloy with 1% Cu contained traces of crystals high in copper. Friedrich and Leroux assume, based on cooling curves under consideration of the eutectic critical points, the saturation concentration at the eutectic temperature of 770° C. with 6% Cu. Due to the incomplete solidification equilibrium during cooling it can, however, be concluded that the copper contents of the solid solution saturated at this temperature is higher. Von Lepkowski observed that an alloy with 5% Cu consisted, after 40 hours annealing at 750° C., of homogeneous solid solutions while an alloy with 6% Cu, after 86 hours annealing at the same temperature, was still heterogeneous. Kurnakow and his collaborators found that the kink in the conductivity isotherms of 25° C. corresponding to the final concentration of the solid solution high in silver, and in the curve of the temperature coefficient of the resistance must be assumed, after 8 hours annealing of the alloys at 550° C., at about 4.9 to 5.7% Cu. The data of the two last-mentioned authors, however, cannot be evaluated quantitatively, as the alloys have been cooled comparatively slowly after annealing, so that as we know to-day a subsequent segregation, more or less pronounced according to the velocity of cooling, can take place. In fact, the more recent measurements of conductivity by Fraenkel and Schaller have shown, contrary to the observations of von Lepkowski, that silver is able to dissolve higher contents of copper after one hour annealing of the alloys at 725° C. and subsequent quenching, the kink in the conductivity isotherms corresponded to a composition of about 9%. The solubility decreases with decreasing temperatures to below 2.84% Cu because an alloy of this composition can still be hardened.

Experimental Data

The alloys were made of purest silver and electrolytic copper and were melted in crucibles under a layer of charcoal, they were cast into rectangular rods with chamfered corners and a square section of 17 mm. length of side. The rods were rolled into square wires of 10 mm. side and annealed (delivery condition[10]). For the heat treatment, pieces of 10 mm. length were used. The samples were annealed in an electric tube furnace through which was passed a strong current of carbon dioxide. A surface oxidation could not be avoided, the microscopic test, however, was made on an area which was at least 2 mm. below the surface. During the annealing of long duration, the temperature was held constant within ±5° C. by a thermostat. Quenching was carried out by taking the samples out of the furnace as quickly as possible and dropping in water. For etching the section the reagent[11] of Norbury[12] was used.

The Curve of the End of Solidification of Solid Solutions High in Silver

Friedrich and Leroux have determined approximately the course of the final solidification curve of the solid solutions rich in silver by means of cooling curves. Since such a determination is always subject to more or less serious errors the curve was determined microscopically. The alloys with 2.55, 4.57 and 6.16% Cu which were homogenized before the examination by 20 hours annealing at 750° C. were heated to the desired quenching temperature. Held at this temperature for 10 to 15 minutes and then quenched. The results of the determination of the structure are given in Table 1 and Figure 1.

The Solubility Curve

The solubility of copper in silver was determined at temperatures of 750, 700, 650, 600, 500, 400, 350, 300 and 250° C. The composition of the alloys used is given in Table 2. At temperatures above 350° C. the equilibrium was obtained by annealing of longer duration at 750° C. where the alloys, except the three highest in copper, consisted of homogeneous solid solutions, and subsequent cooling to the quenching temperature.

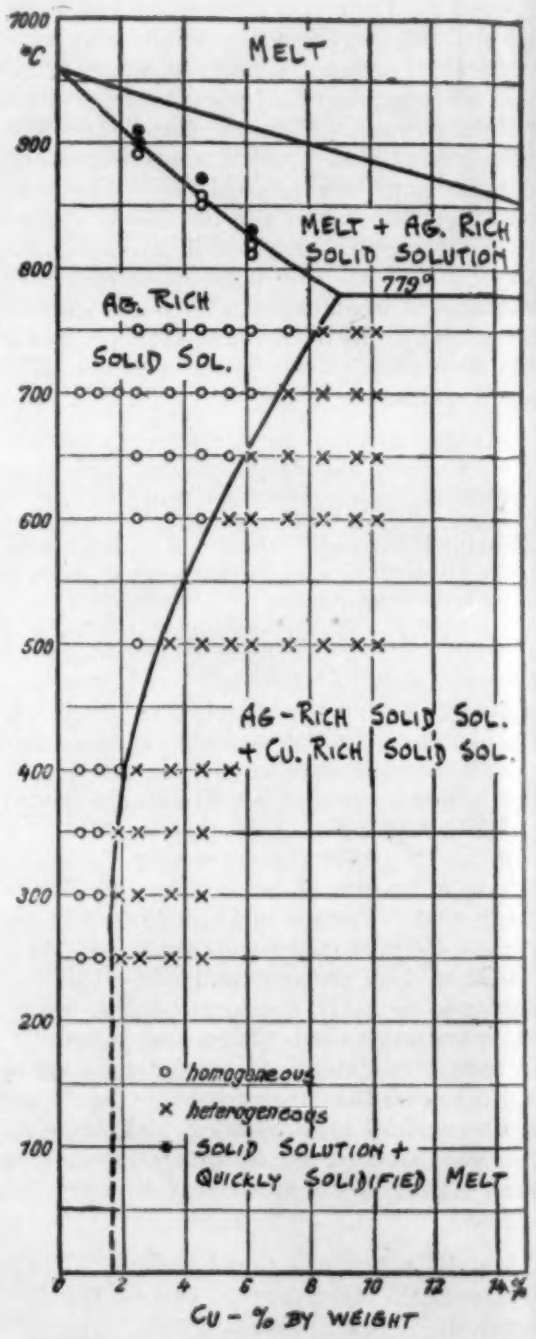

Figure 1—Constitutional Diagram of High Silver Copper-Silver Alloys According to the Author's Investigations

Table 1 Determination of the Solidification Curve of Solid Solutions Rich in Silver

Percent Copper by Weight	Quenching Temperature	Structure
2.55	892°	Homogeneous solid solution
2.55	900°	Solid solution and very little melt
2.55	910°	Solid solution and melt
4.57	853°	Homogeneous solid solution
4.57	858°	Homogeneous solid solution
4.57	872°	Solid solution and melt
6.16	812°	Homogeneous solid solution
6.16	820°	Homogeneous solid solution
6.16	831°	Solid solution and melt

Table 2 Composition of the Alloys Used in the Determination of the Solubility Curve

No.	Analysis % Ag	% Cu	No.	Analysis % Ag	% Cu
5	99.28	0.68	50	94.47	5.51
10	98.60	1.32	60	93.80	6.16
15	98.04	1.94	70	92.60	7.38
20	97.41	2.55	80	91.46	8.48
30	96.33	3.63	90	90.42	9.55
40	95.42	4.57	100	89.75	10.22

The saturation limit at 350° C. and lower temperatures was determined by annealing the previously quenched samples at 700° or 750° C. The saturation limit at 400° C. was determined by both methods: the result was the same. The heat treatments to which the alloys were subjected are given in Table 3. The result of the investigation of the structure is illustrated by the points of state indicated in Figure 1.

Table 3 Determination of Solubility Curve

Group No.	Alloy (See Table 2)	Quenching Temperature and Time of Annealing	Treatment of Alloy
1	20 to 100	750°; 25 hrs. at 750° ± 2°	.....
2	20 to 100	700°; annealed 20 hrs. at 750° ± 5°, cooled to 700°, held constant 2 hrs. and quenched	.....
3	5–15	Annealed 24 hrs. at 700° ± 5° and quenched	.....
4	20–100	650°; annealed 20 hrs. at 750° ± 5° cooled to 650°, kept there 1 hrs. and quenched	.....
5	20–100	600°; annealed 20 hrs. at 750° ± 5° cooled to 600°, held there 2 hr. and quenched	.....
6	20–100	500°; annealed 20 hrs. at 750° ± 5° cooled to 500°, held 27 hrs. and quenched	.....
7	5–40	400°; annealed 2 hrs. at 750° ± 5° cooled within one day to 400°, held constant one day and quenched	.....
8	5–50	400° ± 5°; 28 hrs.	5–15 as group 3 20–50 as group 1
9	5–40	350° ± 5°; 28 hrs.	5–15 as group 3 20–40 as group 2
10	5–40	300° ± 5°; 6 days	5–15 as group 3 20–40 as group 5
11	5–40	250°; 7 days (salt bath)	5–15 as group 3 20–40 as group 4
12	5–15	200°; 15 days (oil bath)	as group 3

According to Figure 1, the solubility of copper in silver[13] increases from about 1.7% Cu at room temperature to 300° C. to about 9% Cu at the eutectic temperature of 779° C. For temperatures above 400°, the solubility was determined correctly to at least 0.5% Cu, below 400° the accuracy is greater.

The saturation limit at 725° lies at about 7.75%, i. e., below the value assumed by Fraenkel and Schaller on account of conductivity measurements (about 9%). Compared with the values of Johannsson and Linde[14] found by the same method it is shown that the solubility at 750° is a little greater, at 350° a little lower than assumed by these authors. These discrepancies are merely due to the larger number of alloys used in the present investigation since the determination of a solubility curve by the microscopic method and by measuring the electric conductivity lead to the same result if in both cases the same number of alloys is used.[15]

The Microscopic Structure

Figures 2 to 13 show some typical micrographs. Figure 2 illustrates the structure of an alloy which was quenched at temperatures above the solidus curve (solid solution and quickly solidified melt).

The alloys which were quenched in the range of solid solutions rich in silver, i. e., at temperatures above the solubility curve, consist of homogeneous crystallites with pronounced twin formation in part. By approximation of composition and quenching temperature to the solubility curve there occur at the grain borders of solid solutions dark irregular zones not uniformly attacked by the etching solution (Figures 3 and 4) which are due to the segregation during quenching (when passing through the solubility curve). They must, therefore, be considered as highly dispersed precipitations of the solid solutions rich in copper and occur at the grain borders because here the copper contents of the individual crystal is greater than in the inside of the grains, even after annealing because of incomplete equalization of concentration. Reduction of the quenching speed naturally leads to an increase in the number of precipitation zones. With decreasing copper contents of the alloys the trend for segregation of the solid solutions rich in silver during quenching becomes less and less since the beginning of segregation in these alloys lies at temperatures at which the quenching speed exceeds the segregation speed.

In the alloys richer in copper there remained after annealing still undissolved[16] solid solutions rich in copper (Figures 5 and 6). If quenching is sufficiently slow segregation zones occur also in these alloys. If the alloys pass slowly through the temperature where segregation starts, the crystals rich in copper are precipitated in microscopic sizes within the grain (Figure 7).[17] With further reduced quenching temperature the quantity of copper

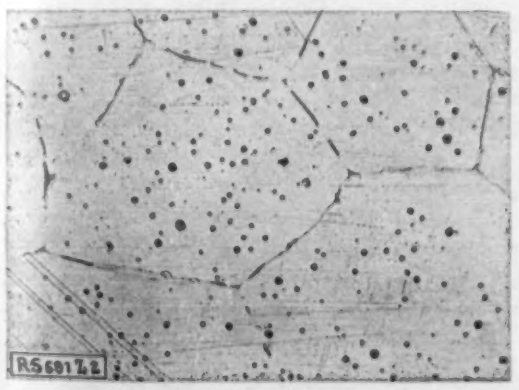

Figure 2—Cu-Ag Alloy with 6.16% Cu. Quenched at 831° C. Magnified 190× (In Original 200×)

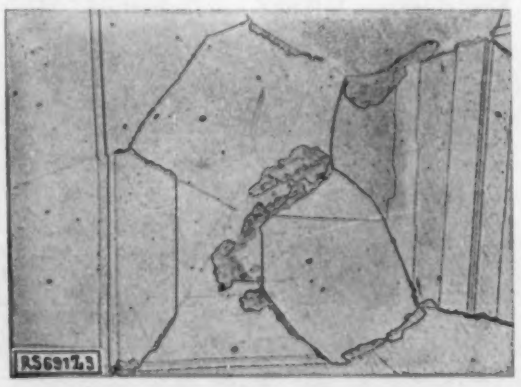

Figure 3—Cu-Ag Alloy with 6.16% Cu. Annealed 20 Hours at 750°±5° C., Cooled to 700°, Held Constant 2 Hours and Quenched. Magnified 190× (200×)

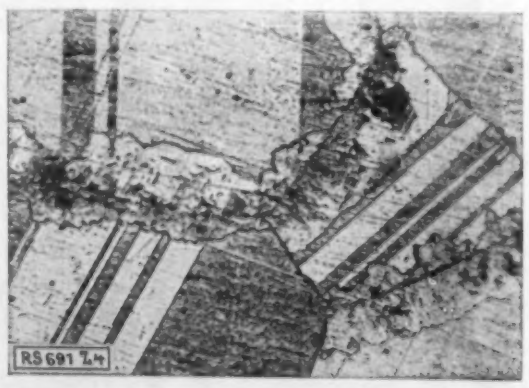

Figure 4—Cu-Ag Alloy with 7.38% Cu. Annealed 25 Hours at 750°±2° C and Quenched. Magnified 190×(200×)

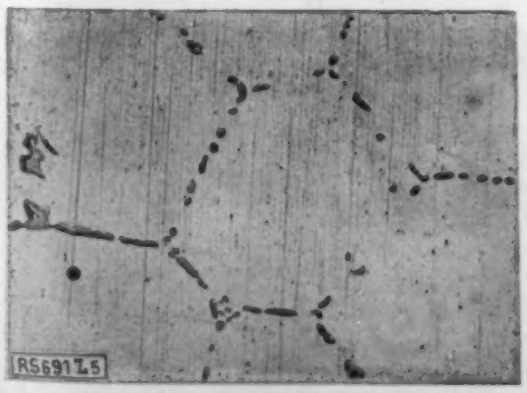

Figure 5—Cu-Ag Alloy with 9.55% Cu. Annealed 25 Hours at 750°±2° C. and Quenched. Magnified 190× (200×)

Figure 6—Cu-Ag Alloy with 10.22% Cu. Annealed 20 Hours at 750°±5°C., Cooled to 700°, Held Constant 2 Hours and Quenched. Magnified 190× (200×)

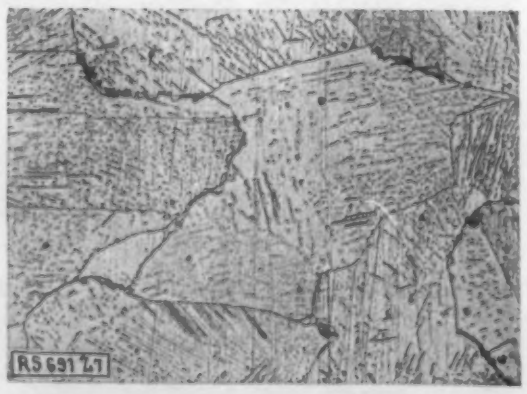

Figure 7—Cu-Ag Alloy with 7.38% Cu. Annealed 20 Hours at 750°±5° C., Cooled to 700°, Held Constant 2 Hours and Quenched. Magnified 190× (200×)

precipitation is greatly increased and finally fills up the whole crystal (Figure 8).[18] Figures 7 and 8 are characteristic for the structure of all alloys which have been cooled after annealing at temperatures above the solubility curve to a temperature within the heterogeneous range. The described segregation occurs, of course, also in those alloys the compositions of which lie, also at high temperatures, within the heterogeneous range (Figure 9).

If alloys quenched at high temperatures are later tempered at temperatures below 400° the crystals rich in copper are precipitated in the shape of very tiny crystals[19] due to the forcibly started segregation (Figures 10–13). Some parts of the segregation zones cannot be resolved even with highest magnification. Only after tempering of long duration does a conglomeration of the small particles into larger crystals take place (Figure 12).

Figures 12 and 13 illustrate that the alloy with 1.94% Cu lies at 300° and lower temperatures within the heterogeneous range. The segregation has not yet been completed after seven days annealing at 250° (Figure 13). By tempering the same alloy at 200° it was not possible, even after annealing of 15 days' duration, to effect a microscopically visible segregation because of the lack of diffusion. Since, at low degrees of over-saturation, the inclination to segregation is especially low, still longer annealing periods will be necessary. It can, however, be assumed with great probability that the solubility does not decrease to any extent below 250°.

Communicated by the Kaiser Wilhelm Institute für Metallforschung.

[1] F. Osmond, *Compt. Rend.*, **124**, 1094–1097, 1234–1237 (1897).
[2] K. Friedrich and A. Leroux, *Metallurgie*, **4**, 297–299 (1907).
[3] W. v. Lepkowski, *Zeitschrift für anorganische Chemie*, **59**, 289–291 (1908).
[4] N. Kurnakow, N. Puschin and N. Senkowski, *Zeitschrift für anorganische Chemie*, **68**, 123–140 (1910).
[5] W. Fraenkel and P. Schaller, *Zeitschrift für Metallkunde*, **20**, 237–243 (1929).
[6] "The Measurements of Conductivity," by A. Matthiessen, *Poggendorfs Annalen*, **110**, 190 (1860); A. Matthiessen and C. Vogt, *Poggendorfs Annalen*, **116**, 369 (1862).
[7] See reference 5 and W. Fraenkel, *Zeitschrift für anorganische Chemie*, **154**, 386–394 (1926).
[8] A. L. Norbury, *Journal of Institute of Metals*, **39**, 145–161 (1928).
[9] After conclusion of the present investigation, C. H. Johannsson and J. O. Linde published in *Zeitschrift für Metallkunde*, **20**, 443–444(1928), the results of solubility measurements of copper-silver alloys according to which the saturation concentration of the high silver solid solutions must be assumed at 750° C. (after 100 hours annealing and quenching) at about 6.2 and 2.4% Cu, respectively.
[10] The production and working of the alloys as well as the analyses was done by the Deutschen Gold- und Silberscheideanstalt, previously Roessler, Branch Plant Pforzheim.
[11] Fifty cm.^{3} of a very dilute solution of chromic acid of a light yellow coloring are mixed with a few drops of concentrated sulphuric acid. Etching is best accomplished by rubbing with a wad of cotton dipped into the solution with constant observation of the ground surface.
[12] See reference 8, page 148; compare also *Zeitschrift für Metallkunde*, **20**, 301 (1928).
[13] The liquidus curve has been taken from the investigations of Heycock and Neville (*Phil. Trans. Royal Soc.*, **189 A**, 32–36, 57–58 (1897), and Friedrich and Leroux. See above.
[14] Compare footnote 9.
[15] This can be shown by the author in another system (not yet published).
[16] The alloy with 8.48% Cu contained, after quenching at 750° C., only very small amounts of solid solutions rich in copper.
[17] The saturation limit at 700° passes between the alloys shown in Figures 3 and 7.
[18] The structure shown in Figure 8 (lamellar precipitations) is similar to that of pearlite.
[19] These conditions have been described in detail by Norbury. (See reference above.)

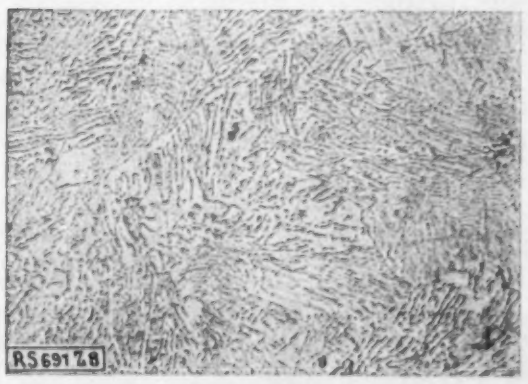

Figure 8—Cu-Ag Alloy with 6.16% Cu. Annealed 20 Hours at 750°±5°C., Cooled to 600°, Held Constant 2 Hours and Quenched. Magnified 285× (300×)

Figure 9—Cu-Ag Alloy with 10.22% Cu. Annealed 20 Hours at 750°±5° C., Cooled to 600°, Held Constant 2 Hours and Quenched. Magnified 190× (200×)

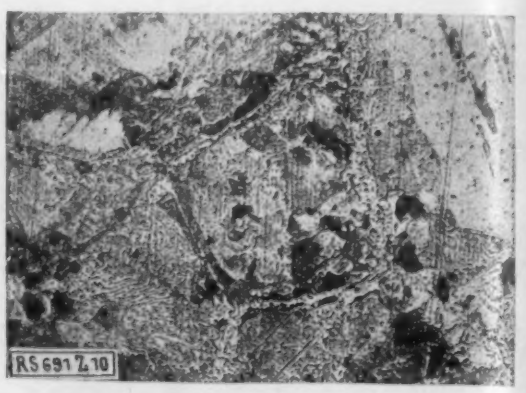

Figure 10—Cu-Ag Alloy with 5.51% Cu. Annealed 25 Hours at 750°±2°C. and Quenched, Then Drawn at 400° for 28 Hours and Quenched. Magnified 190× (200×)

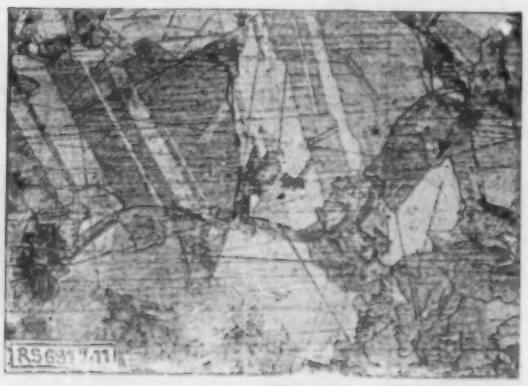

Figure 11—Cu-Ag Alloy with 2.25% Cu. Annealed 20 Hours at 750°±5° C., Cooled to 650°, Held Constant 1 Hour and Quenched. Drawn 7 Days at 250°. Magnified 190× (200×)

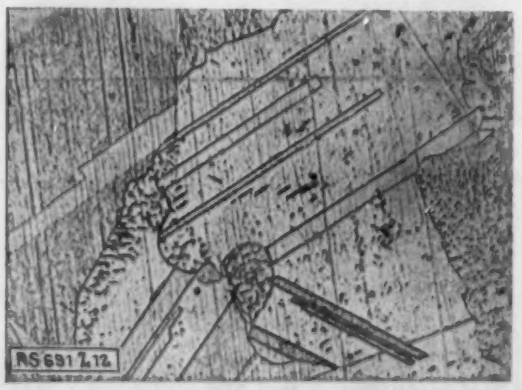

Figure 12—Cu-Ag Alloy with 1.94% Cu. Annealed 24 Hours at 750°±5°C. and Quenched, Then Drawn for 6 Days at 300±5°. Magnified 285× (300×)

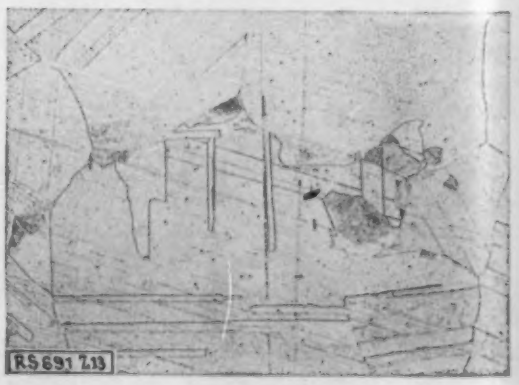

Figure 13—Cu-Ag Alloy with 1.94% Cu. Annealed 20 Hours at 750°±5° C., Cooled at 650°, Held Constant 1 Hour and Quenched. Drawn 7 Days at 250°. Magnified 142.5× (150×)

Book Reviews

Chemical Engineering Catalog. Chemical Catalog Company, New York, 1929. Cloth 9 x 12 inches, 1205 pages. Price, $3.00 postpaid. Free of charge to operating officials subject to return upon publication of new edition.

The fourteenth annual edition of the Chemical Engineering Catalog is divided into the following sections: 1. List of firms whose products are cataloged; 2. Trade Name Index; 3. Classified Index of Equipment and Supplies; 4. Equipment and Supplies Section; 5. Classified Index of Chemicals and Raw Materials; 6. Chemicals and Materials Section; and 7. Technical and Scientific Books Section.

The Chemical Engineering Catalog is a collected, condensed and standardized catalog of data of equipment, machinery, laboratory supplies, heavy and fine chemicals and raw materials used in the industries employing chemical manufacturing processes. The classified indexes of such equipment and materials are carefully cross-referenced. The Technical and Scientific Books Section catalogs and describes briefly a very complete list of books in English on chemical and related books.

A very decided improvement appears in this new issue of the Chemical Engineering Catalog in the Classified Index of Chemicals and Raw Materials. Firms listed in this index are marked to denote suppliers of C. P. and U. S. P. and analyzed chemicals, regular commercial grades or both.

The catalog will give valuable assistance to all who have need for such information.—RICHARD RIMBACH.

American Standards Year Book 1929. American Standards Association, New York, 1929. Paper, $7^3/_4 \times 10^1/_2$, 88 pages.

The Year Book lists about 150 national standards which have been completed and about 175 other national projects now under way. It also lists nearly 550 trade association, technical societies and other organizations which have been cooperating in the establishment of industrial standards under the Association's procedure and approximately 2200 individuals who have been active in the work of the technical committees engaged on the projects.—M. BERG RIMBACH.

Enamels: Their Manufacture and Application to Iron and Steel Ware. BY LAURENCE R. MERNAGH. Charles Griffen & Company, London, 1928. 234 pages, 19 figs. Price, 18 s.

The enameling of iron and steel has never attained especial importance in England as is admitted by the author in stating in the preface, "The most ardent optimist would scarcely consider the story of enameling to be the brightest page in Britain's industrial history.

The American enameler will find that Mernagh has very little new to offer him but this does not mean to imply that the book does not contain much which may prove of value.

—MAX HARTENHEIM.

Trempe Recuit Revenue. Traite theorique et pratique. Volume I. Theorie, 307 pages, 71 plates. Volume II. Pratique, 296 pages, 8 plates. Volume III (in the press). Resultats. Leo Guillet, Membre de l'Institut, Dunod, Paris, 1928.

To the long chain of his well-known works Professor Guillet recently added another link, a three volume series presenting the contemporary state of heat treatment. The author deals with the thermal treatment of metals and alloys. General considerations of alloy equilibria introduce the reader to the phenomena connected with quenching which are then exhaustively treated on the following pages. The changes in quenched metals produced by heating are fully discussed. A comprehensive survey of the methods and apparatus used for treatment follows and the series terminate with the presentation of the results obtainable with different alloys.

The presentation of the subject is remarkable for lucidity and conciseness. A vast amount of detail blends perfectly with the major postulates, not overshadowing them but giving a most desirable relief to wide generalizations. One cannot think about a single question which was not treated somewhere in the pages of the series, even if somewhat briefly. This, however, does not detract from the usefulness of the books because the author, having at his finger tips all metallurgical work of the last quarter of a century freely refers to the original papers giving only the substance of them. It is enough to mention his treatment of duralumin and temper brittleness. The work is limited to purely thermal treatment omitting therefore some well-known but more or less artificial processes as carburizing and similar methods. Ferrous alloys naturally predominate, but all that can be said about the nonferrous group is seemingly said.

The first volume deals with the theory of thermal treatment and is divided practically between the phenomena occurring on quenching and the changes taking place in quenched metals on heating. Out of 300 pages superabundant with diagrams and charts, 234 approach them from every conceivable angle. In no other work is the subject more fully and authoritatively covered, at least to the reviewer's knowledge. The padding with interesting but not closely related facts, so often found in similar treatises, is entirely absent here.

In the second volume the theoretical aspects of the processes are omitted and modern heat treating apparatus and methods of both hemispheres are presented on 293 pages. The work is brought up to date to the extent that such a comparative newcomer as Hump furnace is considered and described as a production apparatus. Furnaces, controlling apparatus and quenching devices are treated adequately. A chapter is given to the difficulties encountered in heat treating and the means for their elimination, a welcome innovation in the books of this type.

It is not easy for a layman to comment on the work of a master, because, as the series has no visible faults, the rest becomes the difference of opinions only. One may think that the subject of alloy steels would gain from the inclusion in the introductory chapter of a few ternary diagrams of the most common alloys. The interest aroused by the possibilities of X-rays might warrant a fuller treatment of their application to metallurgical problems. The eminence of Professor Guillet makes particularly interesting his views on the mechanism of hardening—only slightly touched in the books. One may wince at the delegation of photomicrographs to the end of the book, but this is a purely American point of view evolving from the conceptions generally prevailing in the land of Liberty that the price of a book has nothing to do with its purchase. To anyone wishing to bring himself to the full scope of up-to-minute scientific heat treatment, this series cannot be too strongly recommended.—JOHN D. GAT.

Standards and Standardization. By NORMAN F. HARRIMAN. McGraw-Hill Book Co., Inc., New York, N. Y. 1st Edition, 1928. 265 pages, 15 figs. Price $3.00.

The author states that the purpose of this book is to present a concise account of the more important elements of the science of Standards and Standardization. The subject work is divided into nine chapters and an appendix. By way of introduction, the evolution of standards, industry and standardization from the origin of standards in earliest times to recent developments as exemplified in the enormous consolidations in the business world are dealt with. Two chapters are devoted to standards, their purposes, kinds of units and the importance of maintaining them. Standardization is the main theme of the book. Features of general and of particular considerations in connection with standardization are indicated in a concise and accurate manner. Strict attention is given to scientific, technical and economic accuracy. Quality of standardization and specification writing are discussed with emphasis given to the necessity of making specifications as simple, precise, yet as flexible as possible without impairing their utility. National standardizing bodies and their functioning, and International and National Standardizing Laboratories are described. The general trend of standardization is indicated. A chapter is devoted to Standardization and Coordination of Government Purchases, and some of the work of extreme accuracy of measurements conducted at the United States Bureau of Standards and the instruments used are outlined. The book is well written, is concise and is remarkably free from typographical errors. It contains a splendid bibliography and should be valuable to purchasing agents, technical directors and others responsible for the establishments of standards. The book is included in the McGraw-Hill Industrial Management Series.—W. H. BOYNTON.

Consumption of Tin in United States Increased during 1928

During 1928 the United States consumed 73,270 tons of virgin or primary tin, which was approximately 7.5 percent more than the 68,198 long tons consumed in 1927 and equaled 41 percent of the world's production of approximately 178,000 long tons in 1928, according to a report prepared for the United States Bureau of Mines, Department of Commerce, by J. B. Umhau. Consumers' stocks of tin amounted to 9268 tons on January 1, 1928, and 8587 long tons on December 31, 1928, a net reduction during the year of 681 tons. In addition to virgin tin, 12,106 long tons of secondary metallic tin were used by manufacturers of tin products in 1928. These figures are the result of an inquiry addressed by the Bureau of Mines to manufacturers using metallic tin, of whom 1307 reported consumption.

The statistical canvass shows that new uses of tin have recently been developed in only minor amounts. Some older uses of tin have been discontinued, although the amounts involved are insignificant. Variation in consumption from year to year parallels the fluctuations in demand for the already well-established tin products. For example, the manufacture of bearing metals and solders for motor cars and trucks required 19,000 tons in 1928 compared to 16,000 tons in 1927; the canning industry continues to require the greater portion of the tin plate and also much solder. Growth in the electrical and the more recently developed industries (aeroplane, refrigerators, radio, etc.), while affecting total consumption of bearing metals, solders, etc., has made little change in the proportions required for these basic methods of using tin.

Tin consumed within the great northeastern and north-central manufacturing belt of the United States amounted to 97 percent of the total domestic consumption; New York, Pennsylvania and Michigan, in this territory, consuming over 70 percent of the total. It is within this industrial belt that 75 percent of the total value of all the products of domestic industry is produced.

The consumption of primary tin for tin and terneplate manufacture represents the principal single use for tin in this country, and in 1928 this use accounted for 27,053 long tons, or 37 percent of the total consumption as compared to the 24,525 long tons, or 36 percent, in 1927—a 10 percent difference in favor of the 1928 figure. This increase is due primarily to general industrial expansion and to increased production of canned goods, requiring the greater portion of the tin plate produced. Glass and paper, for containers, serve to some extent as substitutes for tin plate and the attractiveness and utility of these containers may expand their popularity. Aluminum is also replacing some tin which would otherwise be used for tinplate-ware and for tinning and retinning such articles. Non-metallic products, as well as copper, zinc and zinc-coated roofing have undoubtedly supplanted some tin and terneplate used for roofing, siding, etc. Effective economies in the amount of tin required per base box of tin plate manufactured are also tending to reduce the total consumption and to conserve the use of much metallic tin.

Solder, next in importance, required 13,483 long tons of tin, or 18.44 percent of the total consumption in 1928. Compared with the 1927 figures, 13,602 long tons and 19.94 percent, there was a slight decrease. The growing practice of "lap-welding" and die stamping tin cans has lessened the demand for solder in canning operations and consequently for much tin. The practice of "wiping" joints with solder by plumbers, now virtually abandoned on all new construction, has also effected a diminishing demand for solder and hence for tin. Moreover, cadmium is reported proving to be a satisfactory substitute for tin in some solders.

The manufacture of babbitt required 7851 long tons or 10 percent of the total for 1928. This was approximately 4 percent more than the 7595 long tons consumed in 1927 but was a slightly smaller percentage of the consumption of tin for all purposes. The consumpton of tin in the manufacture of bronze decreased 8 percent in 1928, the amounts consumed being 4296 long tons, or 6 percent of the total, in 1928, and 4663.90, or 7 percent of the total, in 1927. Babbitt and bronze bearings are now being replaced by roller and ball bearings.

Although the reported use of tin for tin foil and collapsible tubes was 7933 long tons, or 10 percent of the total tin consumption in 1928 and 6903 long tons in 1927, an apparent gain of 15 percent in 1928, the 1928 figures include data from three concerns whose operations in 1927 were not reported. Consumption by the concerns reporting for both years shows decline in this use of tin. In the collapsible tube and foil industry, aluminum has become a potent competitor of tin and it has been reported recently that zinc, refined electrolytically, shows pronounced ductility and has been used for making collapsible tubes. A transparent cellulose product, "cellophane," which may be had in various colors for wrapping confections, etc., has recently appeared as a substitute for foil.

There was a decided gain in the use of tin for the manufacture of chemicals and oxide. Despite the use of rayon, considerably more silk is being worn. This is the primary reason for the great increase since 1917 in the use of tin for chemicals in the form of "bichloride," "tin salts," "tin-crystals," and "stannous chloride" in the silk industry. Tin oxide is largely used as a constituent of the enamel applied to cooking utensils, refrigerators and sanitary ware. Zirconium oxide, which is cheaper, is used instead of tin oxide by many manufacturers, and in many instances the mixture used is 6 parts tin oxide and 4 parts zirconium oxide. Japanning of the small, cheaper articles, lacquer finishes on refrigerators, and the vitreous china used for sanitary ware instead of vitreous enamels are all factors which tend ultimately to replace considerable tin.

Other important uses for tin were in the making of brass, bronze and other alloys, and in the tinning of wire, bearings, tubes, sheets, etc. In addition, tin has a large number of miscellaneous uses ranging from bottle caps and banjo rings to torches and calf muzzles.

This survey by the Bureau of Mines is the first effort made to ascertain quantitatively the various uses of secondary or metallic tin. The greatest single use of secondary tin is found to be for solder, as 4520 long tons of secondary metal were employed for this purpose in 1928. The secondary tin used for babbitt amounted to 2189 long tons; for bronze, 1112 long tons; for chemicals, 1085 long tons; for type metal, 878 long tons; and for white metal, 785 long tons.

Further data contained in the report relate to the consumption of primary and secondary tin in the United States by various industries for the years 1927–1928; and tin stocks in hands of consumers manufacturing specified commodities on January 1 and December 31, 1928.

Copies of Information Circular 6165, "Consumption of Tin in the United States during 1928," may be obtained from the United States Bureau of Mines, Department of Commerce, Washington, D. C.

"Corundite" refractory products are being largely used in the continuous electric enameling furnace under construction at the Mullins Corporation, Salem, Ohio. "Corundite" refractories have also been chosen for three oil-fired and three electric-continuous furnaces now being built at the Frigidaire Corporation, Dayton, Ohio. All these furnaces are being constructed by the Ferro Enamel Supply Company.

Corundite Refractories, Inc., reports that business, in general, has been unusually good and the outlook for the balance of the year is very promising, business with the enameling trade and kindred lines is far ahead of last year. The demand for "Corundite" protection tubes is unusually heavy. Large shipments of specialties have recently been made, included in which was a large order for the U. S. Assay Office in New York City.

Patent Department

Through an arrangement with Mr. W. M. Corse, Metallurgical Engineer, Washington, D. C., who operates a well-known Patent Information Service, we are able to publish every month a list of important patents in the metallurgical field from the United States, Canada and Europe. The following countries will be included in the European listing: England, Germany, France, Switzerland, Denmark, Norway, Sweden and Italy.

If our readers wish more information about any of the patents listed below they can get it by writing to our Patent Department, and mentioning the fact that they have seen the reference in METALS & ALLOYS. *We will be prepared to mail copies of United States Patents to clients within twenty-four hours of date of issue by special arrangement. Photostatic copies, translations of claims and of full text of foreign patents will be supplied if desired.*

This service is furnished under special arrangement with Mr. Corse's organization at most reasonable rates. Full information can be secured by writing to Patent Department, METALS & ALLOYS, *419 Fourth Avenue, New York.*

United States Patents

Patents issued from September 17 to October 8, 1929, inclusive

Subject of Invention, Patentee, Patent No., and Filing Date

Welding rod (Fe-Cr-V-C). J. R. Dawson, Flushing, N. Y., assignor to Electro Metallurgical Company. No. 1,728,174. Mar. 8, 1924.

Welding rails under traffic. J. H. Deppeler, Weehawken, N. J. No. 1,728,232. Sept. 8, 1928.

Flotation concentration. S. P. Lowe, Denver, Colo., assignor to R. H. Channing, Agent, Denver, Colo. No. 1,728,352. Mar. 26, 1928.

Flotation process. S. P. Lowe, Denver, Colo., assignor to R. H. Channing. Agent, Denver, Colo. No. 1,728,353. Mar. 26, 1928.

Steel-condition-determining apparatus. W. C. Neahr, Denver, Colo., assignor, by mesne assignments, to The Gardner-Denver Co., Quincy, Ill. No. 1,728,358. May 12, 1923.

Process of, and apparatus for recovering volatile metals. B. Ormont, New York, N. Y., assignor to Keystone Chemical & Mfg. Co., Lebanon, Pa. No. 1,728,359. Aug. 1, 1927.

Iron alloy (Fe-Si-Ni-W). J. A. Parsons, Jr., Dayton, O. assignor to The Duriron Co., Inc., New York. No. 1,728,360. Jan. 10, 1929.

Heat-treating furnace. I. J. Shelton, Detroit, and C. V. Jacobi, Grosse Pointe Farms, Mich. No. 1,728,371. Jan. 11, 1929.

Magnetic alloy (Fe-Cr-Si). W. Statham, Smith, Benchams, and H. J. Garnett, Lymne, and J. A. Holden, Sunnyside, England. No. 1,728,451. May 3, 1928, in Great Britain May 13, 1927.

Electric spot-welding machine. D. Kondakjian, Newark, N. J. No. 1,728,616. Dec. 12, 1925.

Process in the manufacture of shapes from steel bars. J. J. Mascuch, E. Orange, N. J. No. 1,728,622. Sept. 21, 1925.

Pyrometer. R. C. Pairman, Berkeley, Calif. No. 1,728,626. June 15, 1927.

Treatment of sulphide ores or sulphidic metallurgical products. F. Johannsen, Clausthal-on-the-Harz, Germany, assignor to the Firm Fried. Krupp Grusonwerk Aktiengesellschaft, Magdeburg-Buckau, Germany. No. 1,728,681. May 28, 1925, in Germany May 30, 1924.

Winning of metals from metal-bearing materials. R. Rodrian, New York, N. Y. No. 1,728,735. June 22, 1927.

Process for the manufacture of refractory substances. J. D'Ans, Berlin, Germany, assignor to Deutsche Gaslühlicht-Auer-Gesellschaft m.b.H., Berlin, Germany. No. 1,728,748. Dec. 24, 1925, in Germany Dec. 24, 1924.

Rotary hearth furnace. E. S. Fatkin, Mansfield, O., assignor to Westinghouse Electric & Mfg. Co. No. 1,728,750. Sept. 19, 1927.

Electric heating unit. H. A. Frietchen, Mansfield, O., assignor to Westinghouse Electric & Mfg. Co. No. 1,728,752. Nov. 6, 1928.

Froth-flotation concentration of ores. C. H. Keller, San Francisco, Calif., assignor to Minerals Separation North American Corp., New York, N. Y. No. 1,728,764. Jan. 11, 1926.

Solder (Pb-Tl). J. Silberstein, Wilkinsburg, Pa., assignor to Westinghouse Electric & Mfg. Co. No. 1,728,772. Sept. 9, 1927.

Method of reducing ores. B. Christiansen, Smedjebacken, Sweden. No. 1,728,784. Dec. 19, 1928, in Sweden Dec. 23, 1927.

Apparatus for line welding. H. W. Tobey, Pittsfield, Mass., assignor to General Electric Co. No. 1,728,812. Aug. 10, 1923.

Manufacture of ductile bodies from highly-refractory metals. J. A. VanLiempt Eindhoven, Netherlands, assignor to General Electric Co. No. 1,728,814. Jan. 16, 1925, in the Netherlands Jan. 24, 1924.

Electric-arc welding. C. L. Ipsen, Schenectady, N. Y., assignor to General Electric Co. No. 1,728,863. Mar. 23, 1927, renewed Feb. 13, 1929.

Auxiliary melting pot. F. M. Joerndt and W. A. Joerndt, Chicago, Ill. No. 1,728,888. Dec. 21, 1927.

Method of making field rings. F. A. Haughton, Schenectady, N. Y., assignor to General Electric Co. No. 1,728,895. Oct. 26, 1926.

Method of making rings from tubing. G. E. Neuberth, Newark, N. J., assignor to Pipe & Tube Bending Corp. of America, Newark, N. J. No. 1,728,897. Oct. 31, 1927.

Method of making tools from hard metal alloys produced by sintering. K. Schröter, Berlin-Lichtenberg, Germany, assignor, by mesne assignments to General Electric Co., Schenectady, N. Y. No. 1,728,909. July 23, 1926, in Germany Dec. 12, 1925.

Method for producing uranium and uranium-zinc alloys. J. W. Marden, E. Orange, N. J., assignor to Westinghouse Lamp Co. No. 1,728,940. Mar. 1, 1926.

Production of rare metals. J. W. Marden and M. N. Rich, E. Orange, N. J., assignors to Westinghouse Lamp Co. No. 1,728,941. Feb. 19, 1927.

Method for producing uranium and uranium-zinc alloys. J. W. Marden, E. Orange, N. J., assignor to Westinghouse Lamp Co. No. 1,728,942. Aug. 20, 1928.

Babbitting jig. R. A. Johnson, Delano, Calif., assignor of one-half to G. Branch, Delano, Calif. No. 1,728,971. July 7, 1928.

Apparatus for use in welding metal. A. Krebs, Boston, Mass. No. 1,728,972. June 21, 1922.

Apparatus for the electrolytic production of metallic powders. M. A. Adam, London, England. No. 1,728,989. Dec. 31, 1925, in Great Britain Jan. 1, 1925.

Vented mold for castings. F. H. Morehead, Boston, Mass., assignor of one-half to F. C. Langenberg, Watertown, Mass. No. 1,729,005. July 3, 1926.

Method and means for separating paramagnetic ores from their diamagnetic contents. H. P. Osborne, C. C. Farmer, and R. B. Teeter, Tacoma, Wash. assignors of one-half to A. A. Crane, Washington. No. 1,729,008. May 21, 1928.

Manufacture of metal strip suitable for turbine blades. C. A. Parsons and E. G. Brownlow, Newcastle-on-Tyne, England; said Brownlow assignor to said Parsons. No. 1,729,009. Jan. 21, 1928, in Great Britain Feb. 7, 1927.

Electrode holder (for welding). A. E. Bicsey, McKeesport, Pa. No. 1,729,059. Dec. 2, 1927.

Material for use in protecting iron and steel. W. H. Cole, Paris, France. No. 1,729,065. Apr. 21, 1927, in Great Britain Mar. 19, 1927.

Tuyère for slag-blowing furnaces. A. Laist, Helena, Mont., assignor to Anaconda Copper Mining Co. No. 1,729,075. Aug. 4, 1928.

Electromagnetic ore separator. D. M. Crist, San Francisco, Calif., assignor to Triumph Steel Co., Reno, Nev. No. 1,729,095. Sept. 30, 1924, renewed Feb. 4, 1929.

Process of pickling iron and steel. I. H. Derby, Indianapolis, Ind., assignor to P. C. Reilly, Indianapolis, Ind. No. 1,729,097. Aug. 30, 1928.

Imitation oxidized surface and process therefor. G. H. Reimer, Fulton, Ill., assignor to Patent Novelty Co., Fulton, Ill. No. 1,729,128. Feb. 13, 1928.

Alloy for high-speed steel. M. S. Clawson, Upper Montclair, N. J. No. 1,729,154. June 26, 1920.

Process for recovery of tin and similar functioning metals from materials containing the same. H. V. Welch, Los Angeles, Calif., assignor to International Precipitation Company, Los Angeles, Calif. No. 1,729,196. Apr. 20, 1927.

Converging jet cutting tip for cutting torches. C. J. Coberly, Los Angeles, Calif., assignor, by direct and mesne assignments, to Kobe, Inc., Los Angeles, Calif. No. 1,729,206. Sept. 29, 1923.

Cutting torch with multiplicity of orifices. C. J. Coberly, Los Angeles, Calif., assignor to Kobe, Inc., Los Angeles, Calif. No. 1,729,207. Original application filed Mar. 17, 1924. Divided and this application filed Sept. 15, 1927.

Alloy and method of working and heat treating the same (Cu-Si). M. G. Corson, Jackson Heights, N. Y., assignor to Electro Metallurgical Co. No. 1,729,208. Oct. 4, 1926.

Metallurgical furnace. B. Talbot, Middlesbrough, England. No. 1,729,230. Dec. 19, 1927, in Belgium June 30, 1927.

Thermostatic element. W. M. Chace, Detroit, Mich.; A. H. Lindley, A. Cooper and Hilma B. Chace, Executors of said W. M. Chace, deceased, assignors to W. M. Chace Valve Co., Detroit, Mich. No. 1,729,245. Dec. 19, 1927.

Diaphragm (rolled sheet Al). C. S. Wickes, Merchantville, N. J., assignor to Victor Talking Machine Co. No. 1,729,305. Dec. 7, 1925.

Alloy of magnesium (Mg-Cd). J. A. Gann, Midland, Mich., assignor to The Dow Chemical Co., Midland, Mich. No. 1,729,339. Oct. 27, 1921.

Method of treating arsenious ore. A. R. Lindblad, Djursholm, Sweden. No. 1,729,351. Dec. 2, 1927, in Sweden July 7, 1927.

Apparatus for preparing molder's sand. G. F. Royer, Wilkes-Barre, Pa., assignor to Royer Foundry & Machine Co., Wilkes-Barre, Pa. No. 1,729,361. May 12, 1928.

Method of manufacturing articles for which a resistibility against the noxious effect of the aged state is required. A. Fry, Essen, Germany, assignor to Fried. Krupp Aktiengesellschaft, Essen-on-the-Ruhr, Germany. No. 1,729,378. Sept. 8, 1926, in Germany Apr. 3, 1926.

Iron alloy (Fe-Cr-Mo-C). A. F. Hilton, Ansonia, Conn., assignor to Farrel-Birmingham Co., Inc., Ansonia, Conn. No. 1,729,386. Jan. 31, 1928.

Iron alloy (Fe-Cu-Mo-C). A. F. Hilton, Ansonia, Conn., assignor to Farrel-Birmingham Co., Inc., Ansonia, Conn. No. 1,729,387. Original Jan. 31, 1928, divided and this application filed Aug. 1, 1929.

Smelting furnace and method of smelting. R. A. Wagstaff, Salt Lake City, Utah, assignor to American Smelting and Refining Co., New York, N. Y. No. 1,729,408. June 27, 1925.

Metal-rolling mill. L. Young, Alton, Ill., assignor to Laclede Steel Co., St. Louis, Mo. No. 1,729,410. July 5, 1928.

Furnace (heat-treating). W. M. Akin and L. Young, Alton, Ill., assignors to Laclede Steel Co., St. Louis, Mo. No. 1,729,411. Oct. 24, 1927.

Extraction of copper-nickel matte. W. J. Harshaw, Shaker Heights Village, and G. L. Homer, Cleveland, Ohio, assignors to The Harshaw Chemical Company, Cleveland, Ohio. No. 1,729,423. Apr. 28, 1926.

Method of welding exposed rails. J. Wattmann, Berlin, Lankwitz, Germany. No. 1,729,464. May 29, 1928, in Germany June 4, 1927.

Process of making briquettes or nonmolded lumps of comminuted minerals for metallurgical purposes and the product of said process. L. L. Simpson, Bryn Mawr, Wash., assignor to New Era Iron and Steel Corp., Seattle, Wash. No. 1,729,496. Nov. 15, 1923.

Apparatus for treating ores. C. A. Brackelsberg, Hemer, Germany, assignor by mesne assignments, to Maguire, Inc. No. 1,729,534. June 17, 1927.

Machine of the semiautomatic type for casting under pressure. E. Brumm, Lyon, France. No. 1,729,536. Dec. 9, 1927, in France Dec. 15, 1926.

Electromagnetic separation or concentration of minerals. W. M. Mordey, London, England. No. 1,729,589. May 8, 1924, in Great Britain May 17, 1923.

Process for electrodeposition of metal. F. K. Bezzenberger, Cleveland, Ohio, assignor, by mesne assignments, to Aluminum Company of America, Pittsburgh, Pa. No. 1,729,607. July 14, 1921, renewed June 7, 1924.

Process of reclaiming scrap metals. T. D. Stay, Cleveland, Ohio, assignor by mesne assignments, to Aluminum Company of America, Pittsburgh, Pa. No. 1,729,631. Oct. 28, 1921, renewed Mar. 24, 1927.

Mold for casting metals. M. Guyot, Cleveland, Ohio, assignor to Aluminum Company of America, Pittsburgh, Pa. No. 1,729,643. Original Apr. 13, 1925, divided and this application filed Aug. 4, 1926.

Toggle drawing press. R. B. Treer, Toledo, Ohio. No. 1,729,658. Aug. 3, 1927.

Sheet mill. J. R. Tytus, Middletown, Ohio, assignor to The American Rolling Mill Co., Middletown, Ohio. No. 1,729,693. May 12, 1925.

Rolling mill. T. R. Akin, St. Louis, Mo., L. Young, Alton, Ill., and F. C. Biggert, Jr., Crafton, Pa., assignors to United Engineering & Foundry Co., Pittsburgh, Pa. No. 1,729,696. Nov. 25, 1927.

Process of roasting iron carbonate ores. A. Apold, Vienna, and H. Fleissner, Leoben, Austria. No. 1,729,697. Nov. 28, 1924.

Method of bonding dissimilar metals. J. V. O. Palm, Cleveland Heights, Ohio, assignor to The Cleveland Graphite Bronze Co., Cleveland, Ohio. No. 1,729,747. Dec. 9, 1925.

Water-cooled port for open-hearth furnaces. S. B. Sheldon, Duluth, Minn. No. 1,729,750. May 4, 1927.

Removal of foreign substances from metal surfaces. C. F. Dindey, Detroit, Mich. No. 1,729,765. Feb. 11, 1925.

Cleaning of metal surfaces. C. F. Dinley, Detroit, Mich. No. 1,729,766. Aug. 14, 1926, renewed Dec. 7, 1927.

Preparation for removing foreign substances from metal surfaces. C. F. Dinley, Detroit, Mich. No. 1,729,767. Original Feb. 11, 1925, divided and this application filed Nov. 30, 1927.

Die-casting machine. A. Sebek, Cicero, Ill., assignor to Krone-Sebek Die Casting & Mfg. Co., Chicago, Ill. No. 1,729,801. Feb. 13, 1928.

Method of making composite castings (steel-cast iron). C. M. Walker, Charlottesville, Va., assignor of one-half to R. L. McElroy and J. E. Shepherd, Charlottesville, Va. No. 1,729,848. Nov. 10, 1926.

Apparatus for separating minerals or other materials. R. E. Trottier, Puteaux, France. No. 1,729,913. May 2, 1925, in France May 12, 1924.

Ruthenium alloy. M. M. Goldsmith and W. H. Falck, Chicago, Ill.; said Falck to Goldsmith Bros. Smelting & Refining Co. No. 1,730,003. Jan. 3, 1927.

Rolling mill. L. Löwy, Düsseldorf, Germany. No. 1,730,012. May 4, 1928.

Puddling iron. J. B. Schlossberg, Terre Haute, Ind., assignor to American Chain Company, Inc. No. 1,730,044. Apr. 26, 1927.

Electric metal-working machine (forging machine). A. L. Bausman, Springfield, Mass., assignor to National Equipment Co., Springfield, Mass. No. 1,730,050. Nov. 4, 1925.

Welding machine. S. A. Eskilson, Stockholm, Sweden. No. 1,730,064. Nov. 6, 1928, in Sweden July 13, 1926.

Coating internally of hollow articles with metal. G. Needle, Coventry, and F. W. Lanchester, Birmingham, England, assignors to The Daimler Co., Ltd., Coventry, England. No. 1,730,097. Feb. 13, 1925, in Great Britain Apr. 22, 1924.

Electric furnace. J. Weintz, Cleveland, Ohio, assignor to The Strong, Carlisle and Hammond Co., Cleveland, Ohio. No. 1,730,103. April 26, 1926.

Method and apparatus for making stools for ingot molds. J. E. Perry, Sharon, Pa., assignor to Valley Mould and Iron Corp., Sharpsville, Pa. No. 1,730,162. July 28, 1926.

Case-hardening process. G. W. Schwab and F. J. Schweizer, Jr., Elizabeth, N. J. No. 1,730,247. Jan. 12, 1926.

Pneumatic jar ramming molding machines. W. Lewis, Haverford, Pa., assignor to The Tabor Manufacturing Co., Philadelphia, Pa. No. 1,730,328. Oct. 12, 1926.

Electrodeposition of chromium. Rudolph Auerbach, Probstdeuben, Germany assignor to Chromeplate, Inc., Union City, N. J. No. 1,730,349. June 22, 1927.

Welder's hood. Michael Stein, Chicago, Ill., assignor to Chicago Eye Shield Company, Chicago, Ill. No. 1,730,390. May 16, 1927.

Fender for ingot molds. Andrew Reed Rowe, Midland, Pa. No. 1,730,384. Jan. 15, 1927.

Butt for sand ramming and the like. Edward W. Stevens, Detroit, Mich., assignor to Chicago Pneumatic Tool Company, New York, N. Y. No. 1,730,393. August 23, 1927.

Electrode holder for electric-arc welders. Carl Waglie, Baltimore, Md., assignor to Charles F. W. Schroeder, Baltimore, Md. No. 1,730,397. June 29, 1927.

Method of uniting metals. Nathan H. Adams, Schenectady, N. Y., assignor to General Electric Company. No. 1,730,443. June 6, 1925.

Apparatus for making pipes. William H. Millspaugh, Sandusky, Ohio, assignor to The Paper and Textile Machinery Company, Sandusky, Ohio. No. 1,730,469. June 6, 1928.

Method of soldering radiator fins. Arthur B. Modine, Racine, Wis. No. 1,730,470. Sept. 25, 1925.

Treatment of iron pyrites. Stanley Isaac Levy, London, England. No. 1,730,514. Feb. 25, 1928.

Apparatus for extracting values from coal and like materials. Frank C. Greene, Denver, Colo., and Irving F. Laucks, Seattle, Wash., assignors to Old Ben Coal Corporation, Chicago, Ill. No. 1,730,569. July 5, 1919.

Muffle furnace. Frank C. Greene, Waukegan, and Otto H. Hertel, Chicago, Ill. No. 1,730,570. June 13, 1925.

Process of operating a hearth-type furnace. Hugh R. MacMichael, El Paso, Texas, assignor to American Smelting and Refining Company, New York, N. Y. No. 1,730,582. June 3, 1927.

Process for treating ores. Ralph F. Meyer, Freeport, Pa., assignor to Meyer Mineral Separation Company, Pittsburgh, Pa. No. 1,730,584. Apr. 16, 1926.

Apparatus for heating solder. William Beddie Robertson, Shanghai, China, assignor to Standard Oil Company of New York. No. 1,730,591. Nov. 19, 1926.

Apparatus for opening tap holes of open-hearth furnaces and the like. James E. Newton, Canton, Ohio, assignor to Central Alloy Steel Corporation, Massillon, Ohio. No. 1,730,678. Nov. 5, 1928.

Process of recovering selenium. Daniel L. Ogden and Roger E. Valentine, Woodbridge, N. J., assignors to United States Metals Refining Company, Carteret, N. J. No. 1,730,681. May 9, 1928.

Cast-iron ingot mold. Robert G. Redmann, Bristol, Conn., assignor to The Sessions Foundry Company, Bristol, Conn. No. 1,730,686. Nov. 15, 1928.

Roasting fines ore. Charles L. Levermore, Rockville Center, Long Island, N. Y., assignor to General Chemical Company, New York, N. Y. No. 1.730,738. Feb. 23, 1928.

Preheater. Arthur R. McArthur, Gary, Ind., assignor to American Sheet and Tin Plate Company, Pittsburgh, Pa. No. 1,730,739. Jan. 14, 1928.

Method of freeing copper from copper oxide. Hiram S. Lukens and Russell P. Heuer, Philadelphia, Pa. No. 1,730,775. Dec. 29, 1924.

Alloy steel. Frederick F. McIntosh, Glen Osborne, Pa., assignor to Crucible Steel Company of America. No. 1,730,780. Jan. 12, 1928.

Method of treating molds. Herbert C. Bugbird, New Brighton, N. Y., assignor to S. D. Warren Company, Boston, Mass. No. 1,730,801. Nov. 1, 1927.

Tempering apparatus. James Carey Davis, Chicago, Ill. No. 1,730,918. Nov. 1, 1926

Purifying pig iron. Fritz Wüst, Düsseldorf, Germany. No. 1,370,960. June 30, 1927.

Bearing-metal alloy. Karl Müller and Wilhelm Sander, Essen, Germany. No. 1,731,021. July 21, 1928.

Method of forming metal castings of metals of different hardness and contractive properties. Cerrol E. Reinhardt, Montreal, Quebec, Canada. No. 1,731,060. Dec. 22, 1925.

Photometer, principally for photographic and pyrometric purposes. Franz Hirschson, Berlin, Germany. No. 1,731,134. Jan. 8, 1927.

Method of casting articles of precious material. Emile Liebert, Los Angeles, Calif. No. 1,731,169. May 14, 1928.

Chromium-plated exhaust valve. William M. Philipps, Birmingham, Mich., assignor to General Motors Corporation, Detroit, Mich. No. 1,731,202. Nov. 16, 1925.

Gold alloy. Victor D. Davignon, Attleboro, Mass., assignor to General Plate Company, Attleboro, Mass. No. 1,731,210. June 10, 1926.

Gold alloy. Victor D. Davignon, Attleboro, Mass., assignor to General Plate Company, Attleboro, Mass. No. 1,731,211. June 10, 1926.

Gold alloy. Victor D. Davignon, Attleboro, Mass., assignor to General Plate Company, Attleboro, Mass. No. 1,731,212. June 23, 1928.

Gold alloy. Victor D. Davignon, Attleboro, Mass., assignor to General Plate Company, Attleboro, Mass. No. 1,731,213. June 23, 1928.

British Patents

(Specifications open to Public Inspection in Great Britain)

Subject of Invention, Patentee, Patent No., and Filing Date

Processes for working up materials containing precious metals. G. Bürg. No. 317,752. Aug. 21, 1928.

Method of producing malleable metal pipes. E. Weir. No. 317,720. Aug. 20, 1928.

Alloys. Westinghouse Electric & Manufacturing Co. No. 317,785. Aug. 22, 1928.

Gas-suction apparatus for mineral furnaces. E. Somoza and P. Loutfoullah. No. 317,727. Aug. 20, 1928.

Process of making cast iron and steel containing copper. Dr. F. Heusler. No. 317,734. Aug. 20, 1928.

Means for grinding mineral ore and the like. J. R. Kueneman. No. 317,769. Aug. 21, 1928.

Method of welding chain links. K. Hüppelshäuser. No. 318,226. Aug. 31, 1928.

Ignition furnaces. Metallges. Akt.-Ges. No. 318,197. Aug. 30, 1928.

Process of rendering utilizable cupriferous and zinciferous ores. Metallges. Akt.-Ges. and Hochofenwerk Lübeck Akt.-Ges. No. 318,232. Aug. 31, 1928.

Process of preliminary refining of pig iron. B. Stürenberg. No. 318,109. Aug. 27, 1928.

Manufacture of iron having good machining properties. F. Borggräfe. No. 318,177. Aug. 31, 1928.

Safety-devices for pipes supplying gas to autogenous welding and like burners. Sulzer Frères Soc. Anon. No. 318,624. Sept. 8, 1928.

Gauging-devices for pyrometers. L. D. J. Tisseyre. No. 318,528. Feb. 8, 1928.

Process for the production of metals of the alkalies or alkaline earths or mixtures of same. Metallges. Akt.-Ges. No. 318,599. Sept. 6, 1928.

Moulding-sand projecting-machines. W. Seidemann. No. 318,990. Sept. 15, 1928.

Apparatus for perforating hollow bodies, such as pipes or the like. Mannesmannröhren-Werke. No. 318,992. September 14, 1928.

Process for increasing the resistance to corrosion of light metal alloys. Dürener Metallwerke Akt.-Ges. No. 318,999. Sept. 14, 1928.

British Patents

(Complete Specifications Accepted)

Subject of Invention, Patentee, Patent No., and Filing Date

Separation of dry materials. K. C. Appleyard, C. W. H. Holmes, I. L. Bramwell and Birtley Iron Co., Ltd. No. 317,802. Feb. 6, 1928.

Separation of dry materials. K. C. Appleyard, C. W. H. Holmes, I. L. Bramwell and Birtley Iron Co., Ltd. No. 317,803. Feb. 6, 1928.

Separation of dry materials. K. C. Appleyard, C. W. H. Holmes, I. L. Bramwell and Birtley Iron Co., Ltd. No. 317,804. Feb. 6, 1928.

Control of the power-factor and voltage conditions of electric induction furnaces. N. R. Davis, C. R. Burch, F. W. Capper, and Associated Electrical Industries, Ltd. No. 317,931. June 5, 1928.

Treating coking-coal and the like with smoke and dust from reduction furnaces. P. L. J. Miguet. No. 292,931. June 25, 1927.

Electric heating-devices for welding, soldering and annealing. E. Schröder. No. 292,985. June 28, 1927.

Internal heating of ore-reducing chambers and other furnaces. H. E. Coley. No. 317,952. July 4, 1928.

Method of protecting cables, pipes, and other metallic bodies against corroding influences. Chemieprodukte Ges. No. 293,835. July 13, 1927.

Process and apparatus for electrolytically manufacturing metal sheets and tubes. E. Kelsen. No. 294,541. July 25, 1927.

Manufacture and production of iron alloys from pulverulent initial materials. J. Y. Johnson (communicated by I. G. Farbenindustrie Akt.-Ges.). No. 317,998. Aug. 31, 1928.

Hot-blast stoves. H. A. Brassert & Co. No. 308,199. Mar. 19, 1928.

Hardening of tool steels. Sir A. Herbert and A. H. Lloyd. No. 318,060. Nov. 28, 1928.

Chromium plating of conducting bodies. Soc. Nouvelle De L'Orfeverie D'Ercuis. No. 303,884. Jan. 12, 1928.

Purifying metals used for castings. A. Kirchhof. No. 318,073. Dec. 28 1928.

Manufacture and production of hollow drill steel. F. F. Gordon. No. 318,266. Mar. 1, 1928.

Thermal disintegration of chrome ores or minerals containing chromium. Bozel-Maletra Soc. Industrielle de Produits Chimiques. No. 288,250. Apr. 6, 1927.

Extrusion presses. A. Kreidler. No. 318,113. Feb. 27, 1928.

Treatment of ores and the like for the separation of metals and their salts. E. A. Ashcroft. No. 318,301. Apr. 5, 1928.

Presses for drawing sheet metal and the like. H. D. Fitzpatrick (Communicated by Press Cushion Co.). No. 318,280. June 1, 1928.

Heat-treatment of oxidized copper ores. T. J. Taplin, B. Taplin and Metals Production, Ltd. No. 318,314. June 5, 1928.

Electrodes for electric furnaces. Soc. Electrometallurgique de Montricher. No. 308,750. Mar. 31, 1928.

Nickel alloys. M. G. Corson. No. 318,359. July 31, 1928.

Method of and means for casting large accumulator plates. W. Haddon and J. A. Fullilove. No. 318,351. July 23, 1928.

Fluxes for joining metals by welding, soldering, or the like. K. Werner and Progress Ges. für Textilmaschinen. No 318,377. Aug. 22, 1928.

Electrolytic production of aluminium. Aluminium Industrie Akt.-Ges. No. 305,458. Feb. 4, 1928.

Annealing-furnaces. International General Electric Co., Inc. No. 300,242. Nov. 9, 1927.

Electrolytic production of aluminium. Vereinigte Aluminium-Werke Akt.-Ges. No. 318,431. Sept. 3, 1928.

Electric furnace. E. Bornand and H. A. Schlaepfer. No. 301,912. Dec. 8, 1927.

Apparatus for the centrifugal casting of hollow metal bodies. J. G. Gaunt (Communicated by Soc. Alti Forni Fonderie Acciaierie e Ferriere Franchi-Gregorini). No. 318,465. June 16, 1928.

Manufacture and production of pure iron. J. Y. Johnson (Communicated by I. G. Farbenindustrie Akt.-Ges.). No. 318,499. April 2, 1928.

Process of treating aluminum or other light metals. Electrolux, Ltd. No. 294,237. July 22, 1927.

Blow-pipes for cutting, welding, and brazing metals. R. A. Ryan, and Hancock & Co. (Engineers). No. 318,703. July 7, 1928.

Welding of rails or the like by means of super-heated molten metal. Elektro-Thermit Ges. No. 318,705. July 10, 1928.

Processes for working-up materials containing precious metals. G. Bürg. No. 317,752. Aug. 21, 1928.

Magnetic separators. H. H. Thompson, A. E. Davies and W. E. Box. No. 318,786. Oct. 31, 1928.

Method of making tubular forgings. J. H. Friedman. No. 318,787. Nov. 1, 1928.

Alloys. A. Pacz. No. 318,802. Nov. 29, 1928.

Galvanizing of steel or iron sheets. G. S. Maliphant and F. J. Rees. No. 318,806. Dec. 8, 1928.

Apparatus for casting metal and like dentures and plates for dental purposes. K. Dehne. No. 318,811. Dec. 28, 1928.

Process of and apparatus for calcining zincblende and the like. Balz-Erzröstung Ges. No. 303,055. Dec. 27, 1927.

Forging and upsetting machines. B. & S. Massey, Ltd., and H. F. Massey. No. 319,065. May 19, 1928.

Mechanical classifiers. E. J. A. Rothelius. No. 318,880. June 11, 1928.

Dynamoelectric generators for electric welding. J. H. St. H. Mawdsley. No. 318,948. June 13, 1928.

Forging-machines. W. L. Clouse. No. 319,131. Sept. 6, 1928.

Magnetic separators. H. H. Thompson, A. E., and W. E. Box. No. 319,156. Oct. 30, 1928.

Nut-blank forging machines. A. De. Fries. No. 319,165. Dec. 11, 1928.

Presses for drawing sheet metal. C. J. Rhodes. No. 319,169. Dec. 17, 1928.

British Patents

(Amended Specifications Published.)

Subject of Invention, Patentee and Patent No.

Bearing metals. Cholewinski. No. 272,889.

Aluminium alloys. Stone & Co., Ltd., J., & others. No. 283,760.

Canadian Patents

Subject of Invention, Patentee, Patent No., and Filing Date

Metal moving method. (*Unloading packs of sheets.*) R. T. Romine, Mount Clemens, Mich. No 292,712. Jan. 24, 1927.

Nozzle for pouring ladles. W. T. Schaup, Swissvale, Pa. No. 292,717. Apr. 3, 1928.

Package. The American Sheet and Tin Plate Company, Pittsburgh, Pa., assignee of H. L. Bodwell and R. M. Withington, Vandergrift, Pa. No. 292,734. May 4, 1928.

Pack opener. The American Sheet and Tin Plate Company, Pittsburgh, Pa., assignee of M. L. McArthur, Gary, Ind., executrix of A. R. McArthur. No. 292,735. Apr. 20, 1929.

Lead dezincing apparatus. The American Smelting and Refining Co., New York, N. Y., assignee of O. Betterton, Omaha, Neb. No. 292,736. Apr. 4, 1927.

Finned tubing manufacture. The Bundy Tubing Co., assignee of W. W. Andersen and A. Gardner, all of Detroit, Mich. No. 292,746. June 8, 1928.

Finned tubing manufacture. The Bundy Tubing Co., assignee of W. W. Andersen and A. Gardner, all of Detroit, Mich. No. 292,747. Nov. 3, 1928.

Mineral concentration. The Electro Metallurgical Ore Reduction Limited, London, England, assignee of F. L. Wilder, E. Morris, E. Schiff, and E. S. King, all of London, England. No. 292,767. Mar. 27, 1928.

Iron-nickel alloy. I. G. Farbenindustrie Akt.-Ges., assignee of C. Muller, Mannheim, and A. Curs and L. Schlecht, Ludwigshafen a.Rh., Germany. No. 292,769. Mar. 18, 1927.

Metal sheet securing method. The Hudson Motor Car Co., Detroit, Mich., assignee of O. J. Grohn, Grosse Pointe Park, Mich. No. 292,784. Aug. 17, 1927.

Froth-flotation concentration of ores. The Minerals Separation North America Corporation, New York, N. Y., assignee of R. B. Martin, Colonia, N. J. No. 292,805. Dec. 28, 1927.

Reducing zinciferous material. The New Jersey Zinc Company, New York, N. Y., assignee of F. G. Breyer and E. H. Bunce, Palmerton, Pa. No. 292,808. July 27, 1927.

Soldering method (*for soldering tungsten or molybdenum*). N. V. Philip's Gloeilampenfabrieken, assignee of A. B. Jonas, both of Eindhoven, Netherlands. No. 292,811. Nov. 4, 1927.

Metallurgical process (*malleabilizing nickel-iron alloys*). The Western Electric Co., New York, N. Y., assignee of J. H. White, Cranford, N. J. No. 292,846. June 1, 1927.

Method of manufacturing containers. (*High-pressure welded containers made of steel containing molybdenum.*) F. Nehl and C. W. Wallmann, both of Mülheim-Ruhr, Germany. No. 292,852. Dec. 29, 1927.

Foundry molding box. A. B. Smith and C. R. Smith, both of Wolverhampton, England. No. 292,870. Apr. 3, 1929.

Electrolytic deposition of thorium. The Canadian Westinghouse Co., Ltd., Hamilton, Ont., assignee of J. W. Marden, East Orange, N. J., J. E. Conley, Denver, Colo., and T. P. Thomas, East Pittsburgh, Pa. No. 292,965. June 28, 1923.

Gold, silver and lead recovery. The Consolidated Mining and Smelting Co. of Canada, Ltd., Montreal, Que., assignee of S. G. Blaylock, J. J. Fingland, and F. E. Lee, Trail, B. C. No. 292,971. May 21, 1928.

Gold, silver and lead recovery. The Consolidated Mining and Smelting Co. of Canada, Ltd., Montreal, Que., assignee of S. G. Blaylock, J. J. Fingland, and F. E. Lee, Trail, B. C. No. 292,972. May 21, 1928.

Process for recovering gold, silver and lead from roasted or oxidized antimonial ores, etc. The Consolidated Mining and Smelting Co. of Canada, Ltd., Montreal, Que., assignee of S. G. Blaylock, J. J. Fingland, and F. E. Lee, Trail, B. C. No. 292,973. May 21, 1928.

Separation of gold, silver and lead from antimonial ores, etc. The Consolidated Mining and Smelting Co. of Canada, Ltd., assignee of S. G. Blaylock F. E. Lee, and P. F. McIntyre, Trail, B. C. No. 292,974. May 21, 1928.

Electron emitter. (*Cathode containing ytrium.*) The Western Electric Co., Inc., New York, N. Y., assignee of J. E. Harris, Newark, N. J. No. 293,029. Oct. 27, 1926.

Process of treating metals to inhibit excess grain growth. The Edward G. Budd Manufacturing Co., assignee of G. L. Kelley, both of Philadelphia, Pa. No. 293,155. Mar. 18, 1925.

Mud gun carriage. J. C. Hopkins and A. Osolin, both of Lakewood, Ohio. No. 293,209. Apr. 10, 1928.

Mud gun. J. C. Hopkins and A. Osolin, both of Lakewood, Ohio. No. 293,210. Apr. 10, 1928.

Combined grizzly and ball mill. A. F. Levitt, Los Angeles, Calif. No. 293,258. Jan. 17, 1929.

Metal pouring apparatus. E. R. Orbin, Duquesne, Pa. No. 293,266. Dec. 18, 1928.

Brick (*refractory*). J. S. Setterberg, Stockholm, Sweden. No. 293,285. Sept. 24, 1928.

Ore enriching method. Aktiebolaget Ferriconcentrat, assignee of H. A. Mueller, both of Stockholm, Sweden. No. 293,303. Sept. 19, 1927.

Mold and core. The Aluminum Company of America, Pittsburgh, Pa., assignee of M. Guyot, Cleveland, Ohio. No. 293,808. Jan. 21, 1928.

Piston (*heat treated aluminum alloy*). The Aluminum Company of America, Pittsburgh, Pa., assignee of G. D. Welting, Cleveland, Ohio. No. 293,310. Jan. 21, 1928.

Process for desilverizing lead bullion. The American Smelting and Refining Co., New York, N. Y., assignee of B. M. O'Harra, Westfield, N. J. No. 293,312. Apr. 10, 1928.

Production of compounded metals (*copper on nickel steel*). The Canadian Westinghouse Co., Ltd., Hamilton, Ont., assignee of E. Romanelli, Bloomfield, N. J. No. 293,331. June 7, 1923.

Fabrication of metallic thorium. The Canadian Westinghouse Co., Ltd., Hamilton, Ont., assignee of W. B. Gero, Bloomfield, N. J. No. 293,332. Apr. 30, 1927.

Electric furnace (*with graphite resistor*). The Harper Electric Furnace Corporation, Philadelphia, Pa., assignee of F. A. J. Fitzgerald, Niagara Falls, N. Y. No. 293,357. May 10, 1927.

Electric furnace resistor (*carbon sheathed with silicon carbide*). The Harper Electric Furnace Corporation, Philadelphia, Pa., assignee of J. Kelleher Chippewa, Ont. No. 293,358. Mar. 19, 1928.

Water-cooled mold for centrifugal casting machines. The Paper and Textile Machinery Co., assignee of H. R. Farnsworth, both of Sandusky, Ohio. No. 293,376. Mar. 2, 1928.

Sand packing device for pipe molds. La Société Anonyme de Hauts-Fourneaux et Fonderies de Pont-a-Mousson, Pont-a-Mousson, Meurthe-et-Moselle, France, assignee of L. L. Mathieue, Rouen, Siene-Inferieure, France. No. 293,389. Mar. 13, 1929.

Pipe casting mold. La Société Anonyme de Hauts-Fourneaux et Fonderies de Pont-a-Mousson, Pont-a-Mousson, Meurthe-et-Moselle, France, assignee of L. L. Mathieue, Rouen, France. No. 293,390. Mar. 13, 1929.

Diaphragm (*pure rolled sheet aluminum*). The Victor Talking Machine Co., Camden, N. J., assignee of C. S. Wickes, Merchantville, N. J. No. 293,405. Dec. 7, 1926.

Mold for artificial stones (*non-corrosive copper-nickel alloy*). J. J. Burke, Chicago, Ill. No. 293,417. June 23, 1928.

Manufacture of hollow metal bars. L. T. Brearley, Sheffield, Yorkshire, England. No. 293,443. July 21, 1928.

Cast wheel (*containing manganese, cast in a rotating mold*). J. C. Davis, Chicago, Ill. No. 293,454. Apr. 17, 1926.

Ingot mold and ingot. E. Gathmann, Baltimore, Md. No. 293,463. Jan. 7, 1929.

Machine for separating and accumulating black sand from sluice boxes. J. M. McCracken, Chico, Calif. No. 293,490. Oct. 20, 1928.

Carbon electrode and method of molding the same. The Aluminium Ltd., Toronto, Ont., assignee of the Aluminum Company of America, Pittsburgh, Pa., assignee of V. C. Doerschuk, Massena, N. Y. No. 293,529. Mar. 21, 1929.

Method of an apparatus for annealing. The American Steel and Wire Co. of New Jersey, Pittsburgh, Pa., assignee of O. Tangring, Worcester, Mass. No. 293,535. May 4, 1927.

Chain welding machine. The Cleveland Chain and Manufacturing Co., assignee of E. A. Stuller, both of Cleveland, Ohio. No. 293,560. June 25, 1928.

Self-baking electrode. Det Norske Aktieselskab for Elektrokemisk Industri of Norway, assignee of C. W. Soderberg, both of Oslo, Norway. No. 293,564. Sept. 15, 1926.

Manufacture of steel plates and sections (*heat treatment and equalization of elastic limit in all directions*). The Martinel Steel Co., Ltd., Liverpool. assignee of F. G. Martin, Higher Bebington, Cheshire, and A. T. Wall, Oxton, Cheshire, England. No. 293,592. May 3, 1926.

Steel (*reduction of oxygen content*). F. G. Griffiths, Massillon, Ohio, assignee of F. C. Langenberg, New York, N. Y., and M. A. Grossmann, Canton, Ohio. No. 293,646. Jan. 12, 1928.

Reduction of ores. The Granular Iron Company, New York, N. Y., assignee of J. W. Hornsey, Oakes-in-Norton, Sheffield, England. No. 293,647 Sept. 11, 1925.

Soaking pit. H. C. Ryding, Birmingham, Ala. No. 293,648. July 15, 1927

Danish Patents

Subject of Invention, Patentee, Patent No., and Filing Date

Metal electrode for electric arc welding and cutting. La Soudure Autogene Française, Paris, France. No. 40,589. Oct. 28, 1926, in France Oct. 30, 1925.

Process for working up pyrites. G. W. Gray and S. I. Levy, London, England. No. 40,671. Feb. 29, 1928.

Process for the production of a stable foam on acid baths. J. H. Gravell, Ambler, Pa. No. 40,679. Mar. 27, 1928, in the United States Mar. 29, 1927.

Process for refining minerals. O. Röhn, Darmstadt, Germany. No. 40,680. May 16, 1928, in Germany June 20, 1927.

Process for making a corrosion-resistant ferrous alloy. Fried. Krupp Akt.-Ges., Essen, Germany. No. 40,745. Jan. 24, 1927, in Germany Feb. 18, 1926.

Arc welding apparatus using a protective gas. Allgemeine Elektricitäts Gesellschaft, Berlin, Germany. No. 40,760. Oct. 18, 1927, in Germany Nov. 9, 1926.

Electric arc welding apparatus. W. R. Hume, Melbourne, Victoria, Australia. No. 40,768. Dec. 23, 1924.

French Patents

Subject of Invention, Patentee, Patent No., and Filing Date

Process for increasing the participation of indirect reduction in the fixation of the oxygen of the ore in blast furnaces. Fried. Krupp Akt.-Ges., Friedrich Alfred Hütte. No. 667,216. Jan. 10, 1929.

Process for annealing steel. H. Hanemann. No. 667,217. Jan. 10, 1929.

Apparatus for the extraction of volatile metals from their ores. H. E. Coley. No. 667,259. Jan. 11, 1929.

Process for purifying foundry metals. A. Kirchhof. No. 667,295. Jan. 12, 1929.

Improvements to machines for rolling metal tubing, bars and the like. Imperial Chemical Industries, Ltd. No. 667,206. Jan. 10, 1929.

Improvements in the electrolytic deposition of metals. Imperial Chemical Industrie, Ltd. No. 667,252. Jan. 11, 1929.

Method of making joints in lead piping. Mouren Fils et Gendre. No. 667,317. Jan. 12, 1929.

Improvements in the heating or melting of metals, alloys or ores by means of induced electric currents. Electric Furnace Co. No. 667,396. Jan. 14, 1929.

Improvements in the electrolytic deposition of metals. Imperial Chemical Industries, Ltd. No. 667,404. Jan. 14, 1929.

Process for the treatment of ores and minerals, especially complex ores and other floatable substances or mixtures of substances. W. Schafer, and Erz u. Kohle Flotation G.m.b.H. No. 668,065. Jan. 28, 1929.

Heat resistant alloy. Oesterreichische Schmidstahlwerke Akt.-Ges. No. 668,009. Jan. 25, 1929.

Ingot-heating furnace. Freidrich Siemens Akt.-Ges. No. 668,038. Jan. 26, 1929.

Process for the treatment of complex ores of minerals and of substances and metalliferous mixtures containing zinc. W. Schafer and Erz u. Kohle Flotation G.m.b.H. No. 668,066. Jan. 28, 1929.

Process for treating copper-rich material. S. I. Levy and G. W. Gray. No. 668,093. Mar. 9, 1928.

Improved treatment of iron pyrites. S. I. Levy and G. W. Gray. No. 668,094. Mar. 9, 1928.

Electrolysis of ferrous chloride. S. I. Levy and G. W. Gray. No. 668,095 Mar. 9, 1928.

Improvements to the production of irons and steels containing molybdenum. Climax Molybdenum Co. No. 668,119. July 2, 1928.

Method of joining tubing by welding. Mannesmannrohren Werke. No. 667,937. Jan. 23, 1929.

Improvements to welding machines. Compagnie Française pour l'Exploitation des Procédés Thomson-Houston. No. 667,962. Jan. 24, 1929.

Improvements to foundry molding machines. Feuer und Luft Ges. für Luftungsanlagen m.b.H. No. 668,074. Jan. 28, 1929.

Aluminum alloy. R. Muller. No. 669,747. Feb. 16, 1929.

Process for making pure compounds of aluminum, suitable for the production of aluminum. W. Bachmann. No. 669,749. Feb. 16, 1929.

Process and apparatus for the production of metals from their oxides and ores. Trent Process Corporation. No. 669,901. Feb. 20, 1929.

Process for the aluminothermic welding of rail joints. Elektro Thermit G.m.b.H. No. 669,654. Feb. 15, 1929.

Process for rolling fine metallic wire. C. Rotzel. No. 669,753. Feb. 16, 1929.

Method of welding rails aluminothermically by the insert process. Elektro Thermit G.m.b.H. No. 669,764. Feb. 16, 1929.

Installation for welding metals. E. Bornand and H. A. Schlaepfer. No. 669,881. Feb. 19, 1929.

Improvements in the welding of lead or lead alloys. The Expanded Metal Co. Ltd. No. 669,894. Feb. 20, 1929.

Process for the metallization of substances. Siemens & Halske Akt.-Ges. No. 669,903. Feb. 20, 1929.

Multiple draw bench. Les Frères Breguet. No. 669,937. Feb. 13, 1929.

Improvements to electric furnaces. P. L. J. Miguet and M. P. Perron. No. 670,019. June 7, 1928.

Process for improving hollow drill rods and other hollow bars. Mannesmannrohren Werke. No. 670,262. Feb. 25, 1929.

High-strength low-carbon titanium steel, and process for making it. W. Mathesius and H. Mathesius. No. 670,166. Feb. 22, 1929.

Rolling mill. P. Eisner. No. 670,210. Feb. 23, 1929.

Process for improving the physico-chemical properties of cast iron and of large and small castings. L. F. C. Girardet. No. 670,353. Feb. 27, 1929.

Process for purifying cast iron. Union de Commandeurs de Produits Metallurgiques & Industriels. No. 670,535. June 23, 1928.

Improvements to metallurgical furnaces. Société des Electrodes de la Savoie. No. 670,539.

Mechanical forging press. Société d'Études et de Constructions Mécaniques Métallurgiques and G. Boivin. No. 670,545. June 25, 1928.

New construction for electric and other soldering irons. Ateliers de Constructions Electriques de Charleroi. No. 670,369. Feb. 27, 1929.

Cutting and welding torch. L. M. A. Baumier. No. 670,471. Feb. 28, 1929.

Device for supplying one or more arc welding stations from the same generator. Société Anonyme Brown Boveri & Cie. No. 670,213. Feb. 23, 1929.

Improvements to ironless induction furnaces. M. Gliksman. No. 670,441. Jan. 24, 1929.

Process and apparatus for roasting and sintering fine ores and tailings. Société pour l'Enrichissement et l'Agglomeration des Minerais. No. 670,749. Mar. 4, 1929.

Process for case-hardening by nitrization. Electro Metallurgical Co. No. 670,612. Feb. 28, 1929.

Aluminum alloy. Rolls Royce, Ltd. No. 670,818. Feb. 22, 1929.

Device for charging metallurgical furnaces. Société des Electrodes de la Savoie. No. 670,910. Mar. 22, 1928.

Improvements to electrometallurgical furnaces with hollow electrodes. Société des Electrodes de la Savoie. No. 670,911. Mar. 22, 1928.

Process and apparatus for casting all metals in a vacuum. M. E. D. Sorel No. 670,962. July 10, 1928.

New method of joining the component parts of sheet metal objects, especially ice molds. No. 670,696. Mar. 2, 1929.

Process for making copper wire with metallic wrapping. Siemens & Halske Akt.-Ges. No. 670,700. Mar. 2, 1929.

Turn-over molding machine. Firme Gustav Zimmermann. No. 670,711. Mar. 2, 1929.

Process for obtaining inoxidizable nickel plating. A. Levy. No. 670,927. July 4, 1928.

Method of making tight joints between sheets of light metals or alloys, for airplane tanks and other applications. Société Anonyme des Ateliers d'Aviation Louis Breguet. No. 670,966. July 10, 1928.

Optical pyrometer. Société Française Arnoux, Veuve Chauvin & Cie. No. 670,877. June 27, 1928.

Improvements to electric furnaces. Compagnie Française pour l'Exploitation des Procédés Thomson-Houston. No. 670,819. Feb. 26, 1929.

Improvements to galvanoplastic processes. S. Dreyfus. No. 670,965. July 10, 1928.

Improvements to apparatus for heating bars, tubing and similar articles by electricity. E. Northrup. Mar. 6, 1929.

Aluminum solder. W. Reuss. No. 35,450. June 21, 1928. (First addition to No. 645,549.)

Improvements to blast furnaces. Société Anonyme des Anciens Etablissements Chavanne-Brun Frères. No. 35,454. June 22, 1928. (First addition to No. 624,475.)

German Patents

Subject of Invention, Patentee, Patent No., and Filing Date

Settling machine. E. J. A. Rothelius, Eskilstuna, Sweden. No. 482,746. Jan. 22, 1927.

Apparatus for the wet separation of minerals. T. M. Davidson, Hatch End, England. No. 482,747. Mar. 20, 1927.

Process for the decomposition of ores. Bayerische Berg-, Hütten- und Salzwerke Akt.-Ges., Munich, Germany. No. 482,748. Dec. 16, 1925.

Multiple wire-drawing machine for drawing in a cooling liquid. Berkenhoff & Drebes A.G., Asslar, near Wetzlar, Germany. No. 482,864. Apr. 22, 1927.

Method of and apparatus for preparing rings, chains, etc., of heavy wire, for soldering. E. G. Bek, Pforzheim, Germany. No. 482,865. Sept. 9, 1926.

Process for making briquettes of hot sintered material. Maschinenfabrik Fr. Gröppel C. Lührig's Nachfolger, Bochum, Germany. No. 482,786. Nov. 11, 1924.

Electrical heating element. Siemens Elektrowärme Gesellschaft m.b.H., Sörnewitz, near Meissen, Germany. No. 482,810. July 31, 1927.

Current washing-device. C. Clouwez, Lille, France. No. 483,401. Mar. 26, 1925.

Deck for a pneumatic ore-dressing table. H. M. Sutton, W. L. Steele, and E. G. Steele, Dallas, Texas. No. 483,354 Feb. 13, 1926.

Drive for universal rolling mills. H. Stüting, Witten a.d. Ruhr, Germany. No. 483,117. May 24, 1927.

Drive for pilger rolling mill trains. Siemens-Schuckertwerke Akt.-Ges., Berlin-Siemensstadt, Germany. Jan. 26, 1928.

Coupling for rolling mills. Deutsche Edelstahlwerke, A. G., Bochum, Germany. No. 483,211. Aug. 25, 1927.

Holding device for the accessories of rolling-mill housings. Mannesmannröhren-Werke, Düsseldorf, Germany. No. 483,405. Dec. 10, 1927.

Device for conveying rolled material from a roller bed which is divided into two parts, on to the heating bed. Demag Akt.-Ges. No. 483,406. Apr. 2, 1926.

Device for handling rolled material on cooling beds. Demag Akt.-Ges. No. 483,109. Jan. 3, 1928.

Means for facilitating the forward motion of rolled strip in guide channels by means of compressed air. Demag Akt.-Ges. No. 483,118. Aug. 12, 1928.

Guides for bar-shaped rolled material. T. Weymerskirch, Differdingen, Luxembourg. No. 483,452. Oct. 21, 1928.

Wheel-disk rolling mill, in which the distance of the axis of the work from the working rolls is variable. A. Friederici, Köln-Mülheim, Germany. No. 483,200. Aug. 13, 1927.

Charging device for shaft furnaces, especially roasting furnaces. Siegener Akt.-Ges. für Eisenkonstruktion, Brückenbau und Verzinkerei, Geisweid, Kr. Siegen, Germany. No. 483,119. May 15, 1928.

Process for the direct production of iron and steel or other ferrous alloys. E. G. T. Gustafsson, Stockholm, Sweden. No. 483,149. Nov. 21, 1926, in Sweden Nov. 28, 1925.

Method of operating gas-heated industrial furnaces, especially regenerative open-hearth furnaces. W. Eckolt, Danzig, Germany. No. 483,396. Sept. 2, 1925.

Lining material for metallic melting crucibles. Allgemeine Elektrizitäts Gesellschaft, Berlin, Germany. No. 483,341. Mar. 27, 1928, in the U. S. Mar. 3, 1927.

Shockless jar molding machine. W. Lewis, Haverford, Pa. No. 483,294. Sept. 23, 1926, in the U. S. Sept. 23, 1925.

Molding machine for grate bars, with stripping plate for models of different sizes. H. Schweitzer, Neumünster, Germany. No. 483,295. July 16, 1926.

Sprinkling device for molding sand and the like. F. K. Axmann, Köln-Ehrenfeld, Germany. No. 483,371. Mar. 24, 1928.

Method of pouring metal into centrifugal casting machines through a pipe which is given a rotary and longitudinal motion with respect to the mold during casting so as to deliver the metal tangentially to the mold. Buderus'sche Eisenwerke, Wetzlar a.d. Lahn, Germany. No. 483,373. July 16, 1927.

Method of casting steel on to steel bodies. Firma Fritz Krieger, Saarbrücken, Germany. No. 483,424. July 3, 1927.

Mold conveyor for foundries. The Gabler Manufacturing Co., Cleveland Ohio. No. 483,372. Sept. 17, 1926, in the U. S. Sept. 19, 1925.

Rabbler tooth for furnaces for roasting zinc blende. Balz-Erzröstung, G.m.b.H., Gleiwitz, Germany. No. 483,427. June 15, 1926.

Rotary furnace for carrying out exothermic reactions. T. Lang, Frankfurt a.M., Germany. No. 483,428. Feb. 6, 1927.

Recovery of copper or lead from their oxidic, oxidized or roasted ores. F. Dietzsch, Kingston-on-Thames, England. No. 483,429. Oct. 28, 1927, in Great Britain Dec. 8, 1926.

Furnaces for refining zinc ashes. F. Schreiber, Düren, Rhld., Germany. No. 483,430. Oct. 17, 1926.

Removal of iron from materials, especially alloys, containing iron. W. Kroll, Luxembourg and M. Lissauer & Cie, Köln, Germany. No. 483,431. Dec. 19, 1928.

Annealing metals or alloys in salt baths. W. Hammer, Freiburg i.Br., Germany. No. 483,432. Apr. 6, 1928.

Process for chromium-plating non-metallic objects. E. D. Feldman, Berlin, Germany. No. 483,312. Mar. 1, 1928.

Process and appliance for carrying out electrolytic processes continuously. Langbein-Pfanhauser-Werke Akt.-Ges., Leipzig, Germany. No. 483,313. Mar. 4, 1928.

Process for coloring copper and alloys containing copper. H. Debach, Geislingen a.d. Steige, Germany. No. 483,481. May 9, 1928.

Alloy for welding nonferrous metals and their alloys and for brazing heavy metals. L. Rostosky, Berlin, Germany. Nov. 22, 1927.

Apparatus for separating pulverulent minerals of different specific gravity. T. Burger, Nürnberg-Mögeldorf, Germany. No. 483,817. May 18, 1926.

Method of heating blast stoves not having a combustion shaft. Vereinigte Stahlwerke Akt.-Ges., Düsseldorf, Germany. No. 483,824. Mar. 31, 1928.

Process and apparatus for producing metallic, especially iron, sponge. F. L. Duffield, London, England. June 3, 1928, in Great Britain Oct. 10, and Nov. 15, 1927. No. 483,825.

Process for producing iron from its ores by chlorination and decomposition of the iron chloride formed with hydrogen. Vereinigte Stahlwerke Akt.-Ges., Düsseldorf, Germany. No. 483,783. May 12, 1927.

Process for the production in the electric furnace of iron and steel alloys directly from ores. H. G. E. Cornelius, Stockholm, Sweden. No. 483,533. Sept. 10, 1925, in Sweden Sept. 24, 1924.

Hearth furnace for melting and reducing ores. W. Mette, Ilmenau, Thür, Germany. No. 483,494. Jan. 5, 1928, in Great Britain Jan. 20, and June 6, 1927.

Electric annealing furnace for strip, wire and the like. E. F. Russ, Köln, Germany. No. 483,643. Aug. 25, 1926.

Switching device for electric welding machines. E. G. Budd Manufacturing Co , Philadelphia, Pa. No. 483,837. Sept. 17, 1924.

Recovery of metals or metallic compounds. I. G. Farbenindustrie Akt.-Ges., Frankfurt a.M., Germany. No. 483,603. Aug. 4, 1927.

Recovery of iron, nickel, cobalt or other carbonyl-forming metals from mixtures which contain several of these metals. I. G. Farbenindustrie Akt.-Ges., Frankfurt a.M., Germany. Feb. 25, 1927.

Recovery and concentration of ekamanganese. Siemens & Halske Akt.-Ges., Berlin-Siemensstadt, Germany. No. 483,495. June 19, 1925.

Production of mixtures of metallic and non-metallic materials. Braunschweiger Hüttenwerk G.m.b.H., Braunschweig, Germany. No. 483,604. Dec. 13, 1928.

Magnetic nickel alloy. W. S. Smith, Benchams, Devonshire; H. J. Garnett, Lymne, Kent; and J. A. Holden, Sunnyside, Essex, England. No. 483,541. Jan. 28, 1927, in Great Britain Sept. 8, and Dec. 17, 1926.

Italian Patents

Subject of Invention, Patentee, Patent No., and Filing Date

Process for the mechanical preparation of iron ore, blast-furnace dust, roasted pyrites, and other materials which in the natural state are weakly paramagnetic. Aktiebolaget Ferriconcentrat, Stockholm, Sweden, assignee of H. A. Mueller. No. 262,119. Sept. 14, 1927, in Sweden Oct. 28, 1926.

Rotary melting furnace which may also be used for refining the molten material. W. Buess, Hannover, Germany. No. 262,311. Aug. 27, 1927.

Process for the preparation of pure iron from iron carbonyl by thermal decomposition. I. G. Farbenindustrie Akt.-Ges., Frankfurt a.M., Germany. No. 261,994. July 4, 1927. (First addition to No. 244,790.)

Process for improving the surface of cast ferrous objects to make them more resistant to fire, acids, alkalies and mechanical agencies. W. Klepsch, Aussig, Czechoslovakia. No. 262,371. Aug. 11, 1927.

Arrangement of rolling mill mandrel. Mannesmannrohren Werke., Düsseldorf, Germany. No. 262,268. Sept. 5, 1927, in Germany June 14, 1927.

Improvements in the extrusion of metals. E. Mitchell, Manchester, England. No. 262,365. Aug. 3, 1927, in Great Britain Sept. 23, 1926.

Process for making tires or other objects which are subject to heavy wear. H. J. van Royen, Hörde, Westfalen, Germany. No. 262,488. Sept. 16, 1927, in Germany Sept. 17, 1926.

Process for the production of high-conductivity, high-strength aluminum alloy wire. Société Anonyme pour l'Industrie de l'Aluminium, Neuhausen. Switzerland. No. 262,110. Sept. 19, 1927, in Switzerland May 21, 1924.

Process for making hollow bodies of expanded sheet metal. C. Traverso, Rivarolo-Genova, Italy. No. 262,370. Aug. 11, 1927.

Method and apparatus for casting hollow objects having the form of a solid of revolution. A. Possenti and C. Scorza, Pesaro, Italy. No. 261,976. May 31, 1927. (First addition to No. 233,621.)

Method and apparatus for casting hollow objects having the form of a solid of revolution. A Possenti and C. Scorza, Pesaro, Italy. No. 262,029. Sept. 5, 1927. (Second addition to No. 233,621.)

Apparatus for electroplating articles in bulk, in which the vessel containing the articles rotates about an inclined axis. F. Kirschner and J. Hess, Vienna, Austria. No. 262,011. July 21, 1927. (First addition to No. 254,480.)

Process for protecting metals against the action of sulfur, especially for protecting electrical conductors such as copper cables and the like in contact with insulating material containing sulfur. F. Kirschner and J. Hess, Vienna, Austria. No. 262,016. July 27, 1927. (First addition to No. 254,429.)

Method and device for accelerating the cooling in an electric annealing furnace. Akt.-Ges. Brown Boveri & Cie., Baden, Switzerland. No. 262,438. Sept. 9, 1927, in Germany Sept. 10, 1926.

Swedish Patents

Subject of Invention, Patentee, Patent No., and Filing Date

Process for the production of sponge iron. Höganäs-Billesholms Aktiebolaget, Höganäs, Sweden. No. 68,324. Jan. 26, 1926.

Calendar of Meetings

International Acetylene Association, Annual Convention, Congress Hotel, Chicago, Ill., November 13 to 15, 1929.

American Society of Mechanical Engineers, Annual Meeting, Engineering Societies Building, New York, N. Y., December 2 to 6, 1929.

American Society of Refrigerating Engineers, Annual Meeting, New York, N. Y., December 2 to 6, 1929.

National Exposition of Power and Mechanical Engineering, Grand Central Palace, New York, N. Y., December 2 to 7, 1929.

World Power Conference, Second Plenary Meeting, Berlin, Germany, June 16 to 25, 1930.

American Society for Steel Treating, Semi-annual Meeting, New York, N. Y., February 14 to 15, 1930.

American Electrochemical Society, 57th Meeting, St. Louis, Mo., May 29 to 31, 1930.

Personals

Arnold Pfau, formerly connected in a consulting capacity with the Globar Corp., has recently taken charge of the electric division of the Bellevue Industrial Furnace Co., Detroit. This company has added an electric furnace division to their plant, manufacturing a line of combustion furnaces.

The American Iron and Steel Institute medal, for the best paper presented at last year's meeting, was awarded to E. S. Sperry for his paper on non-destructive testing.

Edmund S. Davenport, formerly metallurgist with the Westinghouse Lamp Co., Bloomfield, N. J., is now located with the U. S. Steel Corporation Research Laboratory at Kearny, N. J.

Alexander L. Field has severed his connections with the Union Carbide & Carbon Research Laboratories to become associated with the Simonds Saw and Steel Co. as research engineer. His headquarters will be at Lockport, N. Y., where he will be in charge of experimental and development work on electrometallurgical processes and particularly on the electric furnace production of alloy steels. Mr. Field is best known for his investigations on blast furnace slag at the Bureau of Mines, on the effects of zirconium in steel with the Electro Metallurgical Company, on the manufacture of stainless iron with the Central Alloy Steel Corporation.

E. Leitz, Inc., announces the opening of the following offices, 122 South Michigan Ave., Chicago, and 927 Investment Bldg., Washington. It is stated that a complete line of Leitz products will be on display at these offices.

The Ludlum Steel Co. announces that all business in the Cleveland district will be handled from their office at 1593 East Forty-first Street. T. C. Sherman is local manager of the alloy division and W. H. White is local manager of the tool steel division, at the above address.

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Reviews of Manufacturers' Literature

In this department we list each month a selection of the catalogs, books, treatises and other printed matter issued by manufacturers which, in our judgment, should be of interest to the readers of METALS & ALLOYS. *Unless otherwise noted, any of the items listed may be secured free upon application to the issuing firm. Manufacturers who have not yet sent in their printed matter for consideration by the editor of this department are invited to do so, and it is suggested that* METALS & ALLOYS *be placed on the regular mailing list so that advance copies of any material of interest to the metallurgical field may automatically come to this department.*—EDITOR.

Alberene Stone.—Binder containing catalogs as follows: "The Story of Alberene Stone," A. I. A. File No. 22-C; "Alberene Stone Laboratory Equipment," for industrial, educational and research institutions, A. I. A. File No. 35-E-1; "Alberene Stone Developing Tanks," for X-ray, cardiograph and motion picture use, "Alberene Stone Shower Compartments," A. I. A. File No. 22-C-14, etc. Each bulletin is fully illustrated and describes the subjects indicated, contains specifications, typical cross sections and much valuable data. Alberene Stone Co., 153 West 23rd St., New York, N. Y.

Ampco Metal, Its Uses in Modern Industry.—Interesting booklet on the uses of this metal. Many illustrations. Full information. American Metal Products Co., 34th Ave. and Burnham St., Milwaukee, Wis.

"Meehanite Metal."—Booklet containing report of tests conducted by Prof. Enrique Touceda, Albany, N. Y., copy of report of tests conducted by Ordnance Dept. of U. S. Navy, U. S. Bureau of Standards, Government Arsenal of Watertown, Mass. Ross-Meehan Foundries, Chattanooga, Tenn.

Corundite Refractory Products.—Catalog containing valuable information in connection with the use of standardized clay fire brick and super refractories. Corundite Refractories, Inc., Massillon, Ohio.

Falls Electric Furnaces.—Attractive loose-leaf catalog describing and illustrating Falls formed direct-radiating sheet units, type-B Falls electric furnaces, type-H Falls electric furnaces, Falls refractory element holders and fastening bolts. Also contains engineering cooperation on special applications, and blueprint showing phantom view of a "pan" type conveyor furnace. Falls Electric Furnace Corp., 660 Grant St., Buffalo, N. Y.

Die Casting Employed for Making Wide Variety of Parts.—Reprint from the *Iron Trade Review*, by Herbert R. Simonds. The Newton Die Casting Corp., 146 Munson St., New Haven, Conn.

Maehler Ovens (Conveyor Types).—Bulletin No. 16 is devoted to the three types of conveyors, namely, horizontal type continuous conveyor ovens, semi-continuous or intermittent conveyor ovens and multiple pass conveyor ovens. Profusely illustrated. Diagrams of installations. The Paul Maehler Co., 2210 West Lake St., Chicago, Ill.

Leitz Catalog No. 1057.—This publication is devoted to the large Leitz metallographic equipment which has been used extensively in industrial and educational institutions. The publication covers 33 pages and includes a number of photo-micrographs of the data pertaining to each—the latter indicating the particular specimen, the etching solution, the optical equipment, etc., with which each specimen was taken as well as various developing solutions, etc. Numerous illustrations indicating the details of construction are shown. A number of standard equipments adapted for research or routine investigations are carefully outlined. The publication is most interesting, both from a technical as well as instructive viewpoint. E. Leitz, Inc., 60 East 10th St., New York, N. Y.

"Nichrome the Heat-Resisting Alloy."—Booklet containing photographs showing the great diversity of uses in which "Nichrome" castings and sheet containers are profitable. Fully described. Driver-Harris Company, Harrison, N. J.

Rockwell Furnaces.—Loose-leaf binder containing full set of bulletins on this subject. Fully illustrated and descriptive of subjects indicated. Contains also steel heat-treatment chart, data on specific heats and melting points, heat equivalents, conversion table of equivalents, conversion table of constants of heat transmission and conduction. W. S. Rockwell & Co., 50 Church St., New York, N. Y.

American Electric Furnaces.—Looseleaf binder containing Bulletins as follows: "Model HB-High Temperature for Heat Treating High Speed Steel," "Model P-Pot Furnaces for Lead, Salt and Cyanide," "Cylindrical Pot Type," "Rectangular Pot Type," "Box Type," " 'American' Industrial Electrical Furnaces" for all purposes up to 2000° F., " 'American' Electric Vitreous Enameling Furnaces." American Electric Furnace Co., Boston, Mass.

Tobin Bronze and Other Anaconda Copper Alloy Welding Rods and Methods of Application.—Publication B-13. Booklet containing much interesting and valuable data on this subject. Illustrated. Temperature color chart. Table of melting points of Anaconda Welding Rods. The American Brass Company, Waterbury, Conn.

Published by the same firm, "Everdur (a copper-silicon-manganese alloy); Welding Properties and Methods of Procedure." Publication E-4. Also "Everdur, an Alloy of Copper, Silicon and Manganese." Publication E-2."

The Improved Kemp System.—Catalog explaining application and operation of this apparatus used for industrial process heating. Profusely illustrated. Table of capacities. Specifications. The C. M. Kemp Mfg. Co., 405 E. Oliver St., Baltimore, Md.

Misco.—Catalog containing interesting data in word and picture of this high temperature alloy. The Michigan Steel Casting Co., Detroit, Mich.

Published by the same firm, Bulletin No. 1, "Misco Chain for Use at High Temperature;" Bulletin No. 2, "Roof Guides, Replaceable Wearing Strip Type;" Bulletin No. 4, "Misco for Cracking Still Service;" Bulletin No. 5, "Misco High Temperature Alloy Sheet Containers."

Ryan Standard Equipment.—Loose-leaf binder containing bulletins and engineering data on the Ryan low pressure oil burner, low pressure air distributing systems, the Ryan system of combustion and control in the use of fuel oil for steam power generation, Ryan gas or oil-fired crucible melting furnaces. Also pyrometric control instruments, combustion and pressure control switchboards, etc. Diagrams. Illustrations. Ryan, Scully & Company, 3711 Wissahickon Ave., Philadelphia, Pa.

Non-Corrosive and Heat-Resisting Steels.—Bulletin revised to September, 1929, containing much useful and valuable information. Halcomb Steel Company, Syracuse, N. Y.

Published by the same firm, "Marathon for Long Runs."

Calite Alloys.—Booklet describing complete group of heat-enduring and corrosion-resisting materials is unique in setting forth complete physical properties for these materials over the entire operating temperature range and especially the publication of recommended safe working fibre stresses at various temperatures to facilitate the work of the designing engineer. The Calorizing Co., Wilkinsburg Station, Pittsburgh, Pa.

Published by the same firm, Bulletin No. 1-A, "Calorized Pressed Steel Pots;" Bulletin No. 2, "Calorized Pyrometer Protection Tubes;" Bulletin No. 3, "Calorized Bolts and Nuts."

Gehnrich Foundry Ovens.—Bulletin illustrating and describing these ovens for core baking, mold drying, pasting, blacking, preheating, aging, normalizing, etc. Gehnrich Oven Company, Inc., Skillman Ave., from 35th to 36th Sts., Long Island City, N. Y.

Tate-Jones Catalogs.—Loose-leaf binder containing information on "Kirkwood" Natural Gas Burners for Boilers, Portable Stationary Rivet Forges, Forging Furnaces, Bolt Heading and Rod Heating Furnaces, Tool Dressing Furnaces and Blacksmith Forges, Oil or Gas Fuel, Overfired Furnaces, specifications. Oil burning equipment. Tate-Jones & Co., Inc., Pittsburgh, Pa.

Bronze Products of Quality for Engineering Purposes.—Catalog illustrating and describing bronze products. Tables of tests, physical properties. American Manganese Bronze Co., Holmesburg, Philadelphia, Pa.

Brown Instruments.—Handsome binder "C" containing catalogs as follows: "Pyrometers," "Flow Meters," "Electric CO_2 Meters," "Tachometers," "Recording Thermometers," "Recording Pressure Gauges," "Automatic Temperature Control," "Resistance Thermometers." Each catalog is profusely illustrated and descriptive of the subjects indicated. Brown Instrument Company, Philadelphia, Pa.

Micro Balances.—Leaflet illustrating and describing these balances. Christian Becker, Inc., 92 Reade St., New York, N. Y.

Automotive Abstracts.—Interesting publication containing abstracts from the automotive publications of the world. Published by the Automotive Abstracts Co., Columbus, Ohio. $3.00 a year.

Special Alloys and Alloy Steels.—A 58-page publication in French gives details as to composition, physical properties, applications, etc., of the various metallurgical products manufactured by the Acieries D'Imphy, Nievre, France and sold in the United States exclusively by the R. Y. Ferner Company. Among the necessary products described in this booklet are: Invar—coefficient of expansion less than 10×10^{-6} per 1° C. Elinvar—modulus of elasticity practically independent of temperature between —100° C. and + 100° C. Fixinvar—Possesses properties of Invar with extreme stability in physical characteristics with time. Silver—has the coefficient of expansion of glass, i. e., 8×10^{-6}. ADR—extremely low coefficient of expansion between 0° and 500°. N58—nickel alloy with high coefficient of expansion of iron. Modulvar—nickel alloy with high coefficient of elasticity. Platinite—same coefficient of expansion as glass; used for lead-in wires in lamps; platinum substitute in some instances. The R. Y. Ferner Company, 1135 Investment Building, Washington, D. C.

Electric Melting Pots.—Bulletin TB-11 illustrates and describes electric melting pots and other electrically heated industrial equipment, such as soldering troughs, thermometer calibration tanks, electrically heated kettles, immersion units, laboratory hot plates, etc. Harold E. Trent Company, 439 No. 12 St., Philadelphia, Pa.

Published by the same firm, "Trent Electric Furnaces." Leaflet TB-20.

Electromet.—Second edition of this interesting booklet published for the purpose of assisting those interested to make a better selection of the alloys most suitable for their work. List of various alloys kept in stock as standard products, briefly stating their composition and offering suggestions for their use in both the ferrous and non-ferrous industries. A few historical statements have been added as matters of possible interest, and the current practice in the utilization of the more important alloys is briefly described. Electro Metallurgical Sales Corp., 30 East 42nd Street, New York, N. Y.

Published by the same firm, "Metals and Ferro Alloys Used in the Manufacture of Steel."

Connersville Bulletins.—Binder containing bulletins as follows: "Rotary Positive Blowers," "Gas Exhausters and Boosters," "Displacement Meters," "Vacuum Pumps" and "Liquid Pumps." All profusely illustrated and descriptive of the subjects indicated. The Connersville Blower Co., Connersville, Indiana.

General Condensed Catalog CC-5.—New Edition. Illustrates and describes the more important fuel-burning and steam-generating equipment. Contains also complete list of C-E Products. Combustion Engineering Corp., 200 Madison Avenue, New York, N. Y.

American Gas Furnace Products.—Binder containing bulletins as follows: Bulletin No. 1-B, "Blowers;" Bulletin No. 3-A, "Gas Forges;" Bulletin No. 4, "Soft Metal Lead Hardening and Cyanide Hardening Furnaces;" Bulletin No. 5, "Melting Furnaces;" Bulletin No. 8, "Heating Machines;" Bulletin No. 12-A, "Carburizing Machines and Furnaces;" each bulletin fully illustrated and descriptive of subjects indicated. Much useful information. American Gas Furnace Co., Elizabeth, N. J.